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BLAST PARAMETERS AND OTHER CHARACTERISTICS OF N5 PROPELLANT.

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N5 propellant	Sympathetic detonation	Critical diameter
Peak pressure	N5 with 10, 30, and 88% water	Critical thickness
Scaled impulse	N5 carpet rolls	Critical height to explosion
TNT equivalency	MK 43-1 rocket grains	Detonation velocity
Sympathetic deflagration		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The peak pressures and positive impulses resulting from detonating in-process and final product forms of N5 in the scaled distance range of approximately 2.5 to 40 ft/lb$^{1/3}$ were measured. Variables considered included booster size and propellant weight and configuration. The MK 43-1 2.75-inch rocket grain registered the greatest TNT equivalency at 9 ft/lb$^{1/3}$; peak pressure was 250%, and scaled positive impulse 145%. All other forms of N5 registered lower airblast readings.

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20. ABSTRACT (Continued)

NS mixed with 10% or 30% water can be detonated. However, despite heavy confinement and a relatively strong booster, a slurry with 88% water did not detonate. NS is subject to sympathetic detonation or deflagration. If strongly boostered, its critical thickness when unconfined is 3/4 inch.

To reduce the chance of a fire transiting to a detonation, NS should be processed in low tensile-strength containers. Additional information concerning various aspects of NS's sensitivity characteristics are also included.

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INTRODUCTION

Background

The U. S. Army Materiel Command initiated a program in 1971 to upgrade the safety standards of new and existing ammunition plants. In support of this program, the Manufacturing Technology Directorate of Picatinny Arsenal developed design standards for hardening protective structures to withstand the effects of the detonation of high explosives. Design and safety engineers require data pertinent to the maximum strength of a blast wave that may originate from any of the propellant or deflagratable materials present in a plant. Since the airblast capabilities of N5 propellant could not be obtained from the available literature, Picatinny Arsenal sought to establish the TNT equivalencies of this material. A summary of this work is included in the Appendix.

Past methods used for plant siting, as well as the design of individual components of explosive manufacturing and related facilities, have been based on gross quantities of explosives or propellants. Present day technology has shown that manufacturing facilities can be built that are both cost effective and safe if design criteria are based on the actual explosive output of the material involved.

A facility designer requires information on the blast pressure-time history characterized by peak pressure and positive impulse data. Since a considerable amount of prior work has been performed in establishing the airblast parameters of TNT, the design information involving the facility designs for other energetic materials can be expressed in terms of TNT equivalency. In this report information is presented for peak pressure, positive impulse, and the TNT equivalencies of both.

Benefits to be realized through this study include significant cost savings (by avoiding overdesign of structures) and improved safety of personnel (by the installation of adequate blast protection). In addition, some limited safety testing of N5 propellant, paste, and slurry was also accomplished.

Objectives

The program objectives are to:

1. Experimentally determine the maximum airblast output peak overpressure, and positive impulse of N5 propellant.

2. Determine the TNT equivalency of N5 propellant by comparing its measured pressure and positive impulse with those produced by the detonation of an unconfined hemispherical charge of TNT.

3. Ascertain if the blast pressures generated by the N5 propellant follow the scaling laws.

4. Determine the susceptibility of N5 propellant to sympathetic detonation or deflagration.

5. Investigate the detonatability of N5 propellant mixed with 10, 30, and 88% water.

GENERAL TESTS

Test Sites

Small-scale tests were conducted at the IITRI Explosives Research Laboratory near LaPorte, Indiana. The test area consists of two concrete blast pads (each 75-ft long by 10-ft wide) which radiate from ground zero (GZ) and are 90° apart (Fig 1). However, some tests used only one blast pad. Six pressure transducers were mounted flush with the top surface of each concrete slab in mechanically isolated steel plates. The cables from the gages are laid inside covered troughs in the concrete. Pressure and impulse measurements were made 8 to 75 ft from the charges. Scaled distances ranged from 2.5 to over 40 ft/lb$^{1/3}$. All N5 charges were set on a steel witness plate located at GZ.

Large-scale tests were performed at Dugway Proving Ground, Dugway, Utah, at a desert site remote from surface obstructions. Two land areas approximately 500 by 40-ft each, radiating at 90° from GZ, were cleared of all brush and leveled (Fig 2). Six pressure gages (located at discrete intervals from GZ in each cleared area) were flush mounted in steel plates which, in turn, were flush mounted to the ground with stakes. Cables from the gages were buried in the immediate area of

the charge, but were laid on top of the ground the rest of the way to the instrumentation trailer. The gage positions ranged from 16 to 170 ft from GZ.

Verification Tests

During the course of this program, several field verification tests were performed to confirm the recording accuracy of the pressure and measuring systems. Each test consisted of measuring the peak pressure and positive impulse from a 0.9- or 1.35-kg (2- or 3-lb) hemispherical Comp C4[1] charge set on a steel witness plate at ground level. Pressure and impulse data obtained from these tests were compared to established TNT hemispherical surface burst data. (The increased energetics of the Comp C4 were taken into account.) All of the gage systems used in these tests have been previously statically calibrated in a laboratory using accepted secondary standards. The laboratory calibrations were used throughout the program. The verification tests indicated that the instrumentation systems were functioning properly.

The resulting peak pressure and positive impulse data from the verification tests are plotted in Figure 3. The close groupings of each set of data points at the various scaled distances provide a good basis for confidence in the proper functioning of the instrumentation system. The line on the left of the graph is a TNT peak pressure curve which is used as a standard. It was generated by Kingery and is based on a hemispherical charge of TNT (Ref 1). The line passing through the scaled impulse data was generated by IITRI for Comp C4. It utilizes a 1.25 factor to convert the weight of Comp C4 to the equivalent weight of TNT (Ref 2). Both of these reference curves are built into the IITRI computer program. All of the TNT equivalencies presented in this report are generated from these reference curves.

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[1]Comp C4 is a plastic explosive consisting of 91% RDX, 2.1% polyisobutylene, 1.6% motor oil, and 5.3% di(2-ethylehexyl) sebacate with a detonation rate of 8040 m/s.

TNT Equivalency

Calculations were made of TNT equivalencies from the test results. TNT equivalency is defined as the ratio of charge weights (i.e., TNT weight divided by test material weight) that will give the same peak pressure (or positive impulse) at the same radial distance from the charge. All of the scaled quantities noted in this report have been corrected to include the weight of the booster, in terms of its equivalent weight of N5, in the total charge weight.

Source of Data

All of the data in this report (unless otherwise referenced) is based on field experimentation conducted by the Engineering Mechanics Division of the IIT Research Institute, Chicago, Illinois. Facsimilies of the field data sheets, together with the raw test data from the blast gages and computer printouts of the TNT equivalencies for individual data points, are contained in Reference 3.

Instrumentation

A complete description of the pressure measuring system, the recording instruments, derivation of the pressure impulse measurements, the data reproduction system, a diagram of the record and reproduction system, and the calibration procedures are contained in Reference 4.

SPECIFIC TESTS

2.75-Inch Rocket Grain MK 43-1

Improvised shelves for holding one, seven, and nine rocket grains were fabricated from ½-in. plywood (Fig 4). The shelves were approximately as deep as the 26¼-in. length[2] of the MK 43-1 rocket grains. Each shelf was oriented at GZ so that the major axis of the 6.25 lb cylindrical grain was aligned with the axis of the north gage line (Fig 1). Each donor grain had a Comp C4 booster packed into one end of its axially centered star-shaped hole (Fig 4a). The boostered end directed the detonation wave toward the north gage line (Fig 1).

[2] Dimension prior to machining (Drawing F-19203-9240828).

Test RG-8 showed that a single 6.25-lb N5 rocket grain boostered internally with 15 gm of Comp C4 (representing 0.5% of the weight of the booster to the weight of the charge, $^{W}b/^{W}c$) would not attain complete detonation. Therefore, a 30-gm Comp C4 booster (1.1% of w/c) was used to initiate each rocket grain in Tests RG-1, -4, -5, and -6 (Table 1 and Fig 5).

The nine-grain or triple-shelf configuration is weaker in TNT equivalency for both pressure and impulse than the single-shelf seven- or one-grain configurations (Fig 6 and 7). Figure 4c shows that the nine-grain arrangement was centrally initiated by a grain on the middle shelf, and that the vertical distance between grains (center-to-center) is 6½ in., whereas the similar horizontal distance between grains is only 3 5/16 in. In addition to the greater vertical air space between shelves, the shelving material offers more protection in the vertical orientation when compared to the horizontal. Consequently, these two modes of attenuation combine to reduce the impact of the donor charge's shock force on the acceptor charges so that their combined scaled blast output is weaker than that derived from either of the single-shelf arrangements.

Surplus all-metal rocket grain skids (Fig 8) were used for tests D-1 through D-3. Each skid contained 8 aluminum shelves; each shelf consisted of 13 V-shaped slots with an N5 grain in every slot. The center grain on each shelf contained a booster inside one end of the star-shaped hole. The skid was oriented to direct the detonation wave toward the odd gage line (Fig 2).

The loaded rocket-grain buggy was severely damaged in Tests D-1 and D-2, even though some of the acceptor grains did not ignite (Fig 9). When the rocket grains were ignited with eight squibs (one per shelf), the burning did not propagate to a detonation (Table 1, Test D-3).

TNT equivalency computations were made for all of the rocket grain configurations. Reproducibility of the blast output for any particular test configuration was not good. Consequently, TNT equivalency was computed for most of the configurations from eye-fit curves through the maximum-valued data points. The highest TNT equivalencies were obtained from a single-grain configuration. Figures 6 and 7 show TNT equivalency as a function of scaled distance. All scaled parameters were computed on the basis of total charge weight, even though some grains did not detonate.

Table 1

2.75-inch MK 43-1 rocket grain tests

Test number	Configuration	Booster weight (kg x 10^{-3})	Charge weight (kg)	Charge weight (lb)	W_b/W_c (%)	Results
RG-1	Single-rocket grain	30 C4	2.83	6.25	1.1	Detonation
RG-4		30 C4	2.83	6.25	1.1	Detonation
RG-5	(Fig 4a)	30 C4	2.83	6.25	1.1	Detonation
RG-6		30 C4	2.83	6.25	1.1	Detonation
RG-8		15 C4	2.83	6.25	0.5	Incomplete ignition
RG-2	Seven-rocket grains	30 C4	19.84	43.75	0.2	Incomplete ignition
RG-9		30 C4	19,84	43.75	0.2	Incomplete ignition
RG-10	(Fig 4b)	30 C4	19,84	43.75	0.2	Incomplete ignition
RG-3	Triple shelves for	30 C4	25.51	56.25	0.1	Incomplete ignition
RG-7	nine-rocket grains	30 C4	25.51	56.15	0.1	Incomplete ignition
RG-11		30 C4	25.51	56.25	0.1	Incomplete ignition
RG-12	(Fig 4c)	30 C4	25.51	56.25	0.1	Incomplete ignition
(D)-1	Full skid	8* 30 C4	294.78	650.00	0.1	Incomplete ignition
(D)-2	(104 grains)	8* 30 C4	294.78	650.00	0.1	Incomplete ignition
(D)-3	(Fig 5)	8* squibs	294.78	650.00	--	Violent burning

*One booster or squib per shelf

N5 Carpet Rolls

Test Configurations

Tests were conducted on cylindrically shaped rolls of N5 sheet propellant 4-in. wide by 0.075 in. thick and of various lengths. They were fired in coiled carpet-roll configurations at the approximate diameters indicated in Table 2. A 30-gm conically shaped Comp C4 booster was located off center, while a 4-in.-long segment of an N5 2.75-in. rocket grain filled the hole in the center of the carpet roll (Fig 10).

Results

The N5 carpet roll detonated when initiated with a 30-gm Comp C4 booster (0.1 to 0.6% w/c). In tests CR-3 through CR-7, the 8- by 8-in. configuration consisted of two 4- x 8-in.-diameter rolls stacked on top of one another. This group had the largest L/D ratio, 1:1, and used only a medium size booster (o.3% of w/c); yet, it yielded the largest scaled blast output at small scaled distances because it benefited from a greater height, 8 in. vs 4 in. for the others. At large scaled distances, the differences in measured blast output between the three configurations are significantly reduced (Fig 12). Figure 13 shows the TNT equivalency based on an average eye-fit curve through the data points.

N5 Strips

Test Configurations

N5 carpet rolls, as previously described were unwound to form strips. Each strip was 25-ft long, 4-in. wide, and 0.075-in. thick. Several booster types and weights were used in an attempt to ignite the strips. For partial confinement tests S-2 and S-3, a steel plate was placed over the sheets at the boostered end (Fig 11).

Results

The results of the N5 strip tests are summarized in Table 3. When initiated, a small portion of the boostered end was blown away; the remaining N5 strip failed to ignite. When ignited by a black powder bag, the 25-ft length of three N5 sheets burned slowly. These tests showed that even three strips of N5 propellant totaling 0.025-in. thick will not sustain a detonation wave.

Table 2

N5 carpet roll tests

Test number	Configuration Height (in.)	OD (in.)	L/D	Booster weight (gm)		Charge weight (lb)	W_b/W_c %	Results
CR-1	4	8	1/2	30	C4	11.07	0.6	Detonation
CR-2	4	8	1/2	30	C4	11.28	0.6	Detonation
CR-11	4	8	1/2	30	C4	10.89	0.6	Detonation
CR-12	4	8	1/2	30	C4	10.89	0.6	Detonation
CR-13	4	8	1/2	30	C4	10.92	0.6	Detonation
CR-3	8	8	1/1	30	C4	22.44	0.3	Detonation
CR-4	8	8	1/1	30	C4	21.41	0.3	Detonation
CR-5	8	8	1/1	30	C4	21.41	0.3	Detonation
CR-6	8	8	1/1	30	C4	21.91	0.3	Detonation
CR-7	8	8	1/1	30	C4	21.78	0.3	Detonation
CR-8	4	17	1/4.25	30	C4	47.50	0.1	Detonation
CR-9	4	17	1/4.25	30	C4	48.50	0.1	Detonation
CR-10	4	17	1/4.25	30	C4	49.50	0.1	Detonation

Table 3

N5 strip tests

Test number	Configuration	Charge Length (ft)	Initiator/Igniter	Booster (wt/gm)	Results
S-1	One strip*	25	Line-wave generator	250	No initiation
S-2	Three strips, partly confined	25	Line-wave generator	250	No initiation
S-3	Three strips, partly confined	25	Black powder	10	Slow burn
S-4	Three strips	25	Line-wave generator	250	No initiation
S-5	Three strips	25	Detasheet	10	No initiation
S-6	Three strips	25	Line-wave generator	125	No initiation
S-7	Three strips	25	Line-wave generator	125	No initiation

*A strip is 0.075 in. thick and 4 in. wide.

N5 Paste With 10% Moisture

Shipping Drums

Fiber shipping drums[3] containing a paste made from N5 propellant and 10% water were tested in the configuration sectioned in Figure 14. A hole was made in the bottom center of the drum and a booster, generally conical in shape, inserted. Then a plastic bag filled with N5 paste was loaded into the drum and the lid was set loosely on top. The drum was elevated to clear the blasting cap's lead wires.

The first eight tests listed in Table 4 were conducted to ascertain the sensitivity of N5/10% paste to heat and shock. When ignited by a squib, Test EQ-4, the paste bu[illegible] producing a large ball of fire. In Test EQ-12, a squib ignited 16-oz black powder booster under a 70-lb charge of paste. The paste deflagrated producing a loud report and a large fireball, blowing the drum apart and scattering unburnt N5 in the test area. The base of the drum remained on the witness plate indicating that the paste had not detonated. No usable blast measurements were obtained from either test because of low output.

The N5/10% paste did not react when shocked with a DuPont No. 6 blasting cap or a 2.3-gm tetryl booster in Tests EQ-13 and EQ-14. Small holes were blown out of the bottom of the fiber drums by the booster. However, when tetryl boosters of 5.5 gm (representing 0.02% or greater of the $^{W}b/^{W}c$ were initiated, the paste was detonated producing large fireballs, bending witness plates, and causing large overpressures and impulses (Table 4).

Once the booster is sufficiently large to detonate the N5/10% paste, (0.02% of charge weight) further increases in size will not improve the blast output of the paste, at least within range of booster sizes (up to 0.7%) tested herein as shown in Figure 17.

Charge weights of 35 and 70 lb were shot with 11-gm tetryl boosters (Test EQ-3 used Comp C4). The scaled output from the 35-lb Test EQ-8 ($^{W}b/^{W}c$ 0.07%) was less than that from the 70-lb charge EQ-5 ($^{W}b/^{W}c$ 0.03%). These results indicate that in spite of a slightly larger booster the smaller sized charge of N5/10% paste does not scale. Figure 16 also shows the peak pressures and scaled positive impulses plotted versus scaled distance. Those peak pressures and positive impulses are converted into TNT equivalent values in Figure 17, based on averaged eyefit curves.

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[3]Made from 4-ply fiberboard, 0.056-in. thick.

Table 4

N5/10% moisture tests

Test number	Configuration	Booster Type	Booster wt (kg)	Donor charge weight (kg)	Donor charge weight (lb)	Acceptor charge weights (kg)	w_b/w_c[a] (%)	Results
BQ-4	Fiber drum	Squib[b]		32	70	--	--	Slow burn
BQ-12	Fiber drum	BK pdr	.4535	32	70	--	--	Burned
BQ-13	Fiber drum	No. 6 cap		32	70	--	--	No initiation
BQ-14	Fiber drum	Tetryl	.0023	32	70	--	--	No initiation
BQ-8	Fiber drum	Tetryl	.011	16	35	--	0.07	Detonated
BQ-17	Fiber drum	Tetryl	.0055	32	70	--	0.02	Detonated
BQ-5	Fiber drum	Tetryl	.011	32	70	--	0.03	Detonated
BQ-3	Fiber drum	Comp C4	.227	32	70	--	0.07	Detonated
BQ-15	Fiber drum	Comp C4	.227	32	70	--		
CB-1	Bucket	Comp C4	.1134	11.04	24.34	--	1.0	Detonated
CB-2	Bucket	Comp C4	.1134	11.17	24.64	--	1.0	Detonated
CB-3	Bucket	Comp C4	.1134	11.00	24.20	--	1.0	Detonated
CB-4	Bucket	Comp C4	.1134	11.1	24.44	--	1.0	Detonated
CB-5	Bucket	Comp C4	.1134	11.11	24.50	--	1.0	Detonated
ST-1	Strip	Detasheet	.0945	11.34	25	--	0.8	Detonated
ST-2	Strip	Detasheet	.205	11.34	25	--	1.8	Detonated
ST-3	Strip	Detasheet	.0945	11.34	25	--	0.8	Detonated
ST-4	Strip	Detasheet	.0945	11.34	25	--	0.8	Detonated
ST-5	Strip	Detasheet	.0945	11.34	25	--	0.8	Detonated
BQ-22	Plastic cans	Tetryl	.0055	16	35	16 & 16	0.03	Donor detonated Acceptor at 20" detonated Acceptor at 12' burned
EQ-23	Plastic cans	Tetryl	.0055	16	35	16 & 16	0.03	Donor detonated Acceptor at 5' burned Acceptor at 20' burned
BQ-24	Plastic cans	Tetryl	.0055	16	35	16 & 14	0.03	Donor detonated Acceptor at 3' burned Acceptor at 30' no initiation
BQ-25	Plastic cans	Tetryl	.0055	32	70	32 & 14	0.02	Donor detonated Acceptor at 3'-1" burned Acceptor at 31'-5" no initiation

[a]Booster weight/charge weight x 100, w_b/w_c.

[b]I.E. Dupont De Nemours S65 ignition bead squib.

Charging Bucket and Conveyor Strip

N5 propellant loads in a charging bucket or on a conveyor line were simulated in two different size rectangular boxes fabricated from 1/2-in.-thick plywood for test series CB and ST.

For tests CB-1 through CB-5, a charging bucket holding about 24.5 lb of N5/10% paste was simulated with a box 34-in. long, 7-in. wide and 5-in. high (Fig 15). Initiation was accomplished by a conically shaped 4-oz (1% of w/c) Comp C4 booster which was centrally located on top of the charge (Table 4). Detonation of the propellant produced two significantly different blast fields, one for each perpendicular direction, because of the unequal length of sides (34-in. long vs 7-in. wide). Due to a larger presented area, both peak pressure and scaled positive impulse were greater in the direction normal to the long side of the charge (the north gage line) at scaled distances less than 18 ft/lb[3] (Fig 18). The TNT equivalency, computed from eye-fit curves, is shown in Figure 19.

For the ST series (simulating a conveyor line), a rectangular booster cut from Detasheet[4] (Fig 20) was placed at one end of a box 53-in. long, 12-in. wide, and 2-in. high (Fig 21) holding 25 lb of N5/10% paste. A 3 3/8-oz booster (0.8% w/c) repeatedly initiated the paste in Tests ST-1, -3, -4, and -5. The booster weight was increased to 7 5/16 oz for test ST-2, but the blast output remained the same.

In all tests of the ST series the short side, or "end-on" gage line, saw higher peak pressure and impulse measurements (Fig 22), and higher TNT equivalencies (Fig 23) close-in than did the "side-on" gages. This is attributed to the placement of the booster at one end of the box, thereby imparting a unidirectional detonation wave toward the east gage line at the opposite end.

In addition, the low side-on pressure for the ST series can also be attributed to the lower 2-in. height of the ST box (Fig 21) vs 5 in. for the CB box (Fig 15), which probably prevents the propellant from attaining a full or ideal detonation velocity. For the ST series, a nonideal detonation phenomenon is indicated because: (1) the pressure-time pulses were multipeaked, and (2) the peak-pressure pulse was often not the first peak in the pressure-time pulse.

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[3]Made from 4-ply fiberboard, 0.056-in. thick.

[4]Detasheet C, manufactured by E.I. DuPont De Nemours and Company, is flexible explosive with 65% PETN, 8% NC, and a detonation velocity of 7000 m/sec.

Sympathetic Detonation With 10% Moisture

A sympathetic detonation investigation was conducted with open top 20-gallon plastic garbage cans set on steel witness plates. A 5.5-gm tetryl booster was centered on the bottom interior of each donor can. Placement of the donor and two acceptor cans is shown in Figure 24. N5 paste with 10% moisture was then poured into each can.

In Test EQ-22, a 35-lb donor charge caused detonation of acceptor Charge 2 at 20 in. for a scaled separation distance of 0.5 $ft/lb^{1/3}$, but failed in Test EQ-25 at 0.8 $ft/lb^{1/3}$ with acceptor Charge 2.

The partial burning of acceptor Charge 3 occurred in Test EQ-23 at 20 ft from a 35-lb donor for a scaled separation distance of 6.1 $ft/lb^{1/3}$ (Ref 5). However, at a distance of 31 ft 5 in. from a 70-lb donor (7.8 $ft/lb^{1/3}$), Acceptor 3 was blown over, but did not ignite (Test EQ-25). The results of the four sympathetic tests are given in Table 4. Dash lines in Figure 25 dramatize the three zones: detonation, burning, and no ignition.

The mechanisms by which an acceptor charge will either sympathetically detonate or burn are different. A strong shock is required to sympathetically detonate an acceptor charge of N5/10% paste. The scaled distance for sympathetic burning appears to be a direct function of the size of the donor charge's fireball. No firebrands outside of the fireball were observed. The acceptor charge ignites when engulfed in the fireball of a donor charge.

Peak pressures and positive impulses measured during the sympathetic detonation tests are shown in Figure 26. Scaling for Test EQ-22 was based on a charge weight of 70 lb since one 35-lb acceptor charge also detonated. The peak pressures and positive impulses measured during this test series are almost identical to those measured during the fiber drum configuration shots (Fig 16). These tests proved that N5/10% paste can be sympathetically detonated.

N5/30% Water

A paste made from N5 propellant mixed with 30% water was tested with a Comp C4 booster located at the bottom of a fiberboard shipping drum, similar to the 10% tests (Fig 14).

Very low blast outputs were obtained from the first two tests, EQ-15 and EQ-18. EQ-15 used a booster which was only 0.7% of the charge weight, obviously too weak to detonate N5 mixed with 30%

water. Though the booster weight was substantially increased to 3 lb (4.3% of the 70-lb charge) in Test EQ-18, only a partial initiation was obtained (Table 5).

The second test series used a different lot of NS and larger boosters, up to 5.7% of w/c. Meaningful blast measurements were obtained from tests FD-2 and FD-3, as shown in Figure 27, even though Test FD-3 used the same size booster as in the unsuccessful Test EQ-18. TNT equivalency was computed from the average eye-fit curves drawn through the pressure and impulse data (Fig 28).

N5/88% Slurry

NS propellant mixed with 88% water was tested in the following types of steel containers: 5-gal. cans, 55-gal. drums, boxes, and pipes. Except where otherwise specified, the booster was centered on the bottom (Fig 29). The drums were surrounded by a earth mound for partial confinement (Fig 30).

In the can configuration, the $^{W}b/^{W}c$ varies from 0.6% (Test EQ-1) to a maximum of 2.5% in Test EQ-2. All of the boosters proved inadequate, because the slurry did not react. Nevertheless, for the 55-gal. drum tests (EQ-11, EQ-19, and EQ-20) boosters with a ratio of $^{W}b/^{W}c$ varying from 1.5% down to 0.8% were used (Table 6).

For two tests, the excess water was drained off from the slurry, leaving an estimated 30-to-35% moisture content. Then 37 lb of the solids were placed in a 5-gal. can (Test EQ-7) and 51.5 lb in an 11.5-cu. in., 1/4-in.-thick walled steel box (Test EQ-21, Fig 32). A Comp C4 booster, 2.7% of w/c for the can and 3.9% for the box, was positioned in the bottom center of each container.

After each test, unburned propellant was found in the area. The containers (cans, drums, or boxes) used to contain the propellant were fragmented by the explosive energy of the booster. The witness plates were relatively unbent and did not even show burn marks. Motion pictures showed the booster detonation and then the development of a silver-grayish cloud of unburnt material. There was no indication that the slurry ignited during any of these tests (Table 6).

A stainless steel pipe, 3 1/4-in. ID, (simulating the 4 in. ID pipe in the plant) was loaded with N5/88% slurry. One end was welded with a cap. The booster was placed at the other end which was closed with cellophane, tape, and sealing wax. The pipe was elevated about 2 inches above the witness plate (Fig 32). In tests EQ-6, -10, and -16, the pipe was agitated for 5 minutes at 150 rpm by an electric motor prior to initiation; in Test EQ-9, the N5 was allowed to settle.

Table 5

N5/30% moisture tests

Test number	Configuration	Booster (Comp C4) wt (lb)	Charge wt (lb)	W_b/W_c (%)	Results
EQ-15	Fiber drum	0.5	70	0.7	No initiation
EQ-18	Fiber drum	3.0	70	4.3	Partial initiation
FD-1	Fiber drum	4.0	70	5.7	Detonation
FD-2	Fiber drum	4.0	70	5.7	Detonation
FD-3	Fiber drum	3.0	70	4.3	Detonation

Table 6

N5/88% slurry tests

Test number	Configuration	Booster wt (oz)	Charge wt (lb)	W_b/W_c* (%)	Results
EQ-1	5 gal. can	4	40	0.6	No initiation
EQ-2	5 gal. can	16	40	2.5	No initiation
EQ-11	55 gal. drum	32	200	1.0	No initiation
EQ-19	55 gal. drum	48	200	1.5	No initiation
EQ-20	55 gal. drum	48	400	0.8	No initiation
EQ-7	5 gal. can	16	37 (solids)	2.7	No initiation
EQ-21	Steel box	32	51.5 (solids)	3.9	No initiation
EQ-6	Agitated pipe	8	11.5	4.3	No initiation
EQ-9	Settled pipe	24	11.75	12.8	No initiation
EQ-10	Agitated pipe	24	11.5	13.0	No initiation
EQ-16	Agitated pipe	24	11.5	13.0	No initiation
88%-1	5 gal. can	32	40	5.0	No initiation
2 through 50	5 gal. can	48	40	7.5	No initiation

*W_b/W_c = booster weight/charge weight x 100

Detonation of the booster caused its end of the pipe to fragment and peel back like a banana skin. Though large boosters (13% w/c) were used under conditions of strong confinement in tests EQ-9, -10, and -16, the remaining portion of each pipe was recovered intact indicating no reaction.

On completion of the original investigation, the following recommendation concerning the NS/88% slurry was made (Ref 5): "The most severe configuration, confined settled slurry, should be duplicated and shot a large number of times to confirm the insensitivity of this material."

Subsequently, 50 confirmatory tests were conducted in 5-gal cans (representing mild confinement), each loaded with 40 lb of NS/88% slurry. After the NS solids settled, a 3-lb Comp C4 booster (7.5% w/c), was imbedded in the upper part of the solids, as shown in Figure 29. These tests confirmed that the NS slurry will not react under the stipulated conditions.

During the course of these tests, seven calibration shots (Cal -1 and Cal-3 through -8) using 3-lb Comp C4 cylinders with a 1:1 aspect ratio were fired. These charges were similar in weight and material to that of the booster used in the confirmatory test series (except for Test 88%-1). Therefore, Table 7 compares the peak pressure readings obtained from the calibration firings to those of the boosters.

The peak pressures from the NS/88% slurry shots are, in general, lower than the calibration shots. The average peak pressure at a distance of 13.3 ft for 49 3-lb booster shots is 11.4 psig compared to 12.9 psig for 7 3-lb calibration shots. At a distance of 19.6 ft, the average pressures were 5.7 vs 6.1 psig, respectively. It is concluded that the shock attenuating effect of the contents of the 5 gal can suppressed the blast output of the Comp C4 booster.

Critical Thickness

Odd behavior of the NS propellant was noted during testing. For instance, the entire series of strip tests (Table 3) failed to detonate, even though boosters as large as 250 gm were used. Since 30-gm boosters sufficed to initiate all of the charges made from identical material and similar mass in the carpet roll series (Table 2), this was surprising.

Table 7

N5/88% confirmatory test results

Test number	Booster wt (lb)	Pressure at 13.3 ft (psig)	Pressure at 19.6 ft (psig)
Cal-1	3	13.49	6.25
Cal-2	2	10.5	4.95
N5/88%-01	2	9.5	4.84
N5/88%-02	3	13.37	5.90
N5/88%-03	3	13.88	6.13
N5/88%-04	3	11.92	4.95
N5/88%-05	3	13.14	5.42
N5/88%-06	3	13.14	6.13
N5/88%-07	3	10.70	4.92
N5/88%-08	3	10.70	5.40
N5/88%-09	3	10.33	5.66
N5/88%-10	3	8.94	5.40
Cal-3	3	13.56	5.66
N5/88%-11	3	8.74	5.90
N5/88%-12	3	8.54	4.95
N5/88%-13	3	13.51	6.37
N5/88%-14	3	11.92	5.42
N5/88%-15	3	9.54	5.54
N5/88%-16	3	11.97	6.37
N5/88%-17	3	12.72	6.14
N5/88%-18	3	12.29	5.40
N5/88%-19	3	12.72	6.02
N5/88%-20	3	11.97	5.90
Cal-4	3	12.29	6.14
N5/88%-21	3	12.29	6.14
N5/88%-22	3	12.29	5.40
N5/88%-23	3	12.72	5.66
N5/88%-24	3	11.55	6.37
N5/88%-25	3	10.70	6.01

Test number	Booster wt (lb)	Pressure at 13.3 ft (psig)	Pressure at 19.6 ft (psig)
N5/88%-26	3	12.29	5.90
N5/88%-27	3	9.96	4.72
N5/88%-28	3	10.49	6.13
N5/88%-29	3	11.34	5.40
N5/88%-30	3	10.38	5.90
Cal-5	3	12.93	5.90
N5/88%-31	3	12.29	5.66
N5/88%-32	3	12.08	5.90
N5/88%-33	3	10.49	5.90
N5/88%-34	3	9.75	5.15
N5/88%-35	3	9.96	5.00
Cal-6	3	12.82	5.94
N5/88%-36	3	12.29	6.13
N5/88%-37	3	11.87	5.65
N5/88%-38	3	11.23	5.65
N5/88%-39	3	12.72	5.90
N5/88%-40	3	11.87	5.65
N5/88%-41	3	13.14	6.61
N5/88%-42	3	12.29	5.90
N5/88%-43	3	9.54	4.91
N5/88%-44	3	12.29	5.90
N5/88%-45	3	12.29	5.90
N5/88%-46	3	12.56	5.15
Cal-7	3	12.29	6.37
N5/88%-47	3	12.63	4.90
N5/88%-48	3	12.86	5.90
N5/88%-49	3	9.54	5.90
N5/88%-50	3	10.32	5.40
Cal-8	3	13.13	6.37

An examination of the data shows that the difference lies in the geometric form. The carpet roll's minimum dimensions were 4-in. high by 8-in. diameter, while the maximum dimensions for three strips were 4-in. wide by 0.250-in. thick. The thin strip's inability to propagate signified that the NS propellant was below its critical thickness (the minimum thickness at which a detonation will propagate).

The Allegany Ballistics Laboratory (ABL) in 1969 investigated the critical thickness of NS sheet. These tests showed that unconfined NS will not propagate when the thickness is 1.15 in., even though boosters up to 148 gm are used. However, with a 239-gm booster and a 1.4-in. thickness, the sheet propagated in one of two firings. It is evident that this thickness is a threshold value, because a smaller 44-gm booster failed to initiate a 2.25-in.-thick sheet (Table 8)(Ref 6).

The ABL data indicate that, when partially confined between steel plates, the critical thickness is also 1.4 in. with a 208-gm booster (Table 8). Smaller boosters were not tried at this thickness. The non-propagation of a 6.25-lb MK 43-1 grain when shocked by a 15-gm booster in Test RG-8 was also surprising since 70 lb of NS/10% paste was initiated by a smaller 5.5-gm booster in Test EQ-17. The outside diameter of the MK 43-1 grain is 2.538 in. prior to machining. The following hypothesis explains this oddity: due to the star-shaped hollow center, the hole diameter varies from 0.736 to 1.254 in., which leaves a minimum wall thickness of 1.234 in. As shown previously, this depth of material is below the critical thickness. However, because of a pressure build-up within the grain's hollow core (similar to confinement), the threshold was crossed when a 30-gm booster was used to initiate the charge (Tests RG-1 and RG-4 through -6).

The ST series of tests (Table 4) showed low blast pressures vs the CB series. This indicated that the 2-in.-thick NS/10% paste was above the critical height, but below the ideal height for full high-velocity propagation.

Critical Diameter

In 1967 ABL tested 45 gm of NS/10% paste partly confined in schedule-40 black steel pipes (Fig 33 and 34) 24-in. long and ½ in. in diameter. When initiated by 20-gm boosters (43% w/c), it propagated in three out of three firings. Though smaller diameters were not investigated, the data establishes that the critical diameter (minimum diameter for propagation of a detonation) for confined NS paste with a large booster can be as small as ½ in. in diameter.

Table 8

Critical thickness data for N5 sheet

Status	Booster size[b] (DxL in in.)	Booster weight (grams)	Sample thickness[c] (in.)	Charge L/D	Sample weight (grams)	W_b/W_c (%)	Propagation rate (m/s)	Comments
Confined	3/4 x 4	44	.219	5.3	612	7.2	No propagation	
Confined	3/4 x 4	44	.312	5.3	925	4.8	No propagation	
Confined	3/4 x 4	45	.438	5.3	1246	3.6	No propagation	
Confined	3/4 x 4	45	.472	5.3	1801 & 1854	2.5	No propagation	Two tests
Confined	3/4 x 4	45	.50	5.3	1575	2.9	No propagation	
Confined	3/4 x 4	45	.625	5.3	1890	2.4	No propagation	
Confined	3/4 x 4	43-44	.708	5.3	2106 & 2117	2.1	No propagation	Two tests
Confined	3/4 x 4	46	.75	5.3	2128	2.2	No propagation	
Confined	3/4 x 4	44	.844	5.3	2408	1.8	No propagation	
Confined	3/4 x 4	46	.969	5.3	2763	1.7	No propagation	
Confined	1 x 4	80	1.06	4.0	3013	2.7	No propagation	
Confined	1 x 4	80	1.06	4.0	3178	2.5	7010	
Confined	1 x 4	80	1.06	4.0	2724	2.9	7501	
Confined	1-1/4 x 4-3/4	154	1.22	3.8	3178	4.8	Partial Prop	Burning
Not confined	1-1/2 x 5-1/2	208	1.44	3.7	3749	5.5	Propagation	
Not confined	1-3/4 x 6-1/4	386	2.0	3.6	4780	8.1	7450	
Not confined	3/4 x 4	45	.65	5.3			No propagation	
Not confined	1-1/4 x 4-3/4	148	1.15	3.8			No propagation	
Not confined	1-1/4 x 4-3/4	147	1.15	3.8			No propagation	
Not confined	1-1/4 x 4-3/4	147	1.15	3.8			No propagation	
Not confined	3/4 x 4	44	1.15	5.3			No propagation	
Not confined	1-1/2 x 5-1/2	243	1.4	3.7			No propagation	Some burning
Not confined	1-1/2 x 5-1/2	239	1.4	3.7			Propagation	
Not confined	1-3/4 x 6-1/4	340	1.75	3.6			Propagation	
Not confined	3/4 x 4	45	2.0	5.3			No propagation	
Not confined	2 x 7	574	2.0	3.5			Propagation	
Not confined	3/4 x 4	44	2.25	5.3			No propagation	
Not confined	2-1/2 x 8-1/2	1006-1012	2.5	3.4			Propagation	Two tests
Not confined	2 x 7	517	2.5	3.5			6916	

[a]Confined samples were clamped between flat rectangular steel plates.

[b]Boosters were right circular cylinders of Comp C4 positioned against the edge of the stack of N-5 sheets.

[c]Sample thickness for these tests was varied by stacking rectangular sheets of N-5.

Tests for unconfined propellant in the same geometry were not conducted. However, in a 4 by 24 in. rectangular pile, 32 gm of 1/2-in. thick unconfined paste did not propagate when shocked by a 20-gm booster (62% w/c). When 76 gm of paste 3/4-in. thick was initiated with a 47-gm booster (62% w/c), it did propagate (Table 9, Ref 6). These tests showed that, for the stated level of boostering, the critical thickness is about 3/4 in. In general, smaller boosters could be expected to require a greater thickness of material.

Resistance Wire Probe Test

The resistance wire probe shown in Figures 34 and 35 is used to measure the reaction velocity of a propellant or explosive during critical height to explosion or critical diameter testing. The probe is connected to an oscilloscope so that voltage changes in the tube/resistance wire circuit are monitored. The pressure front accompanying an explosive reaction collapses the aluminum tube onto the resistance wire, producing a change in the circuit resistance and a corresponding change in the magnitude of the input voltage signal to the oscilloscope. The voltage signal, interpreted as container height and expressed as a function of time, provides a velocity profile of the reaction through the entire sample length (Ref 7).

Critical Height to Explosion

ABL investigated the critical height to explosion (minimum height for a given diameter at which burning NS propellant will transit to a detonation) as shown in Figure 35. The data show that NS propellant ignited in a 2-in. diameter by 4-in.-high pipe will burn in three of three trials. If the height is increased to 5 in., an explosion occurs in one of five firings. Changing the diameter to 4 in. and the height to 6 in. resulted in fires in four trials. However, increasing the height to 7 in. yields an explosion in two of three firings. By reducing the confinement from steel to polyethylene, only fires occurred, even though both the height and mass were substantially increased (Table 10, Ref 6).

These tests indicate that the threshold value for the critical height, wherein confined NS can transit from burning to a detonation, is 5 in. for a 2-in. ID and 7 in. for a 4-in. ID pipe.

When ABL ignited NS/10% paste in 2 in. diameter pipe 11 in. high, only burning occurred in seven trials. However, by increasing the height to 12 in., explosions occurred in two of four firings. When the level of confinement was reduced to plastic or canvas, only burning occurred though the size was substantially increased (Table 10, Ref 6).

Table 9

Critical thickness data for N5 paste with 10% water

Status	Booster size (DxL in in.)	Booster (Comp C4) wt (grams)	Container type	Charge (L/D)	Sample thickness (in.)	Sample wt (grams)	W_b/W_c* %	Reaction
Not confined	1/2 x 4	20	4 x 24" rectangular pile	8	1/2	31 & 34	61.5	No propagation in two tests
Not confined	1/2 x 4	20	4 x 24" rectangular pile	8	1/2	32	62.5	Partial propagation
Not confined	3/4 x 4	47	4 x 24" rectangular pile	5.3	3/4	76	62	Propagation
Not confined	1 x 4	83	4 x 24" rectangular pile	4	1	123	68	Propagation
Not confined	1 x 4	79-82	4 x 24" rectangular	4	1	456 & 464	17.5	No propagation in three tests
Not confined	1-1/2 x 5-1/2	245-257	4 x 24" rectangular pile	3.7	1-1/2	727, 683, 724 & 698	35.5	Propagation in four tests
Not confined	2 x 7	578	4 x 24" rectangular pile	3.5	2	504	115	Propagation
Confined	2 x 7	580	Schedule 40 seamless pipe 28" long	3.5	2 (dia)	622	93	Propagation
Confined	1 x 4	81	24" length	4	1	134	60	Propagation
Confined	1/2 x 4	19-20	24" length	8	1/2	44 to 47	43	Propagation in three tests

*W_b/W_c = booster weight/charge weight x 100.

Table 10

Critical height to explosion data for N5 propellant

Container type	Bottom cap	Igniter (black powder)	Igniter location	Sample condition	Container diameter (in.)	Sample height (in.)	Reaction	No. of tests
Schedule 40 seamless pipe	Cast iron	12 gm bag	Bottom	Dry	2	24	Explosion	Eight
					2	23	Explosion	Two
					2	10	Explosion	--
					2	6	Explosion	Two
					2	5	Burning	Four
					2	5	Explosion	--
					2	4	Burning	Three
					4	24	Explosion	Five
					4	9	Explosion	--
					4	8	Explosion	--
					4	7	Explosion	Two
					4	7	Burning	--
					4	6	Burning	Four
					8	24	Explosion	Two
Polyethylene box	Polyethylene				20½ x 17¼	24	Burning	Three
Polyethylene box	Polyethylene		Top		20½ x 17¼	24	Burning	Four
Schedule 40 seamless pipe	Cast iron		Bottom	10% H_2O	2	24	Explosion	Three
			Top		2	24	Burning	--
			Center		2	24	Explosion	Two
			Center		2	24	Burning	--
			Bottom		2	12	Burning	Two
					2	12	Explosion	Two
					2	11	Burning	Seven
					2	10	Burning	--
					2	9	Burning	--
					2	6	Burning	--
					4	24	Explosion	Four
					4	22	Explosion	--
					4	20	Explosion	Two
					4	19	Burning	Two
					4	18	Burning	Three
					4	17	Burning	--
					4	16	Burning	--
Polyethylene box	Polyethylene				18 x 15	22	Burning	Two
			Top		18 x 15	22	Burning	Two
Canvas Bag	None		Bottom outside bag		20 x 24	7	Burning	Two
	None		Center of bag		20 x 24	7	Burning	Two
Unconfined	None		Bottom		12 x 24	3	Burning	Three

These firings explain the outcome of Tests EQ-4 and EQ-12, wherein a squib and black powder were used respectively to ignite 70-lb charges of N5/10% paste. Due to the weak confinement of the fiber drums, the paste did not transit from burning to detonation. The value of utilizing physically weak containers and plumbing (in a plant processing detonatable materials) to prevent a fire from growing into a detonation is indicated by these results.

Critical Height to Explosion Test Procedure

The propellant or explosive is subjected to submerged flame initiation to determine if the material reacts explosively in varying degrees of confinement. Testing is generally conducted using schedule 40 black seamless-steel pipe open at one end as shown in Figure 35. Test variables include the pipe length and diameter and material height within the pipe. Flame initiation is provided by a 12-gm bag igniter consisting of a 50/50 mixture of FFFG black powder and 2056D casting powder and a M100 Atlas match. The reaction velocity is often measured using a resistance wire probe inserted inside and along the length of the container (see Fig 33 and 35). Determination of an explosive reaction occurrence is based upon visual assessment of the container damage or interpretation of the reaction velocity profile (Ref 7).

Detonation Velocity

ABL established the detonation rate for N5 sheet propellant partially confined between two flat steel plates. With an 80-gm booster ($^{W}b/^{W}c$ 2.5%) coupled to 1.06-in.-thick material, the detonation rate was 7010 m/s (Ref 6). For unconfined N5 propellant, 2.5-in. thick, the velocity was 6916 m/s (Table 8). Because the Comp C4 booster weighed 517 gm, this velocity may represent an over-driven condition.

Other Characteristics

N5 propellant has the following additional characteristics:

At 77°F, it has a density of 0.0561 pound mass per cubic inch.

In 1-in. cylinders, it withstood a temperature of 80°C for 15 days without cracking.

The heat of explosion is 850 cal/gm (TNT = 1080); heat of formation, -521 cal/gm at 298K.

It did not react when impacted by a 2-kg weight falling 64 cm on the Bureau of Mines tester (Ref 8).

Badger Army Ammunition Plant (BAAP) ascertains ignition temperatures with a Perkin Elmer Differential Scanning Calorimeter under constant conditions of 10°C/min. with a 10-mg sample. They reported:

NS rocket propellant: ½% H_2O, threshold 180°C, ignition 210°C

NS rocket paste: 8% H_2O, threshold 202°C, ignition 216°C

The principal ingredients of NS are: nitrocellulose 50%, nitroglycerin 35%, and diethylphthalate 10.5% (Ref 8).

CONCLUSIONS

1. Burning NS propellant can transit to a detonation if confined in a 5-in. long by 2-in. diameter (or larger) steel container.

2. NS paste with 30% moisture can be detonated.

3. NS slurry with 88% water will not detonate even with a large booster (13% weight of charge) and under strong confinement.

4. Sympathetic detonation of neighboring MK 43-1 2.75-in. rocket grains on V-shaped shelves may occur.

5. NS carpet rolls can detonate.

6. NS sheets (0.225-inch thick) will not propagate a detonation.

7. Unconfined NS propellant has a critical depth of 3/4 inch when initiated with a very stong booster.

8. There is insufficient evidence to prove that the NS propellant follows the scaling laws for blast pressure.

RECOMMENDATION

To prevent fire from transiting into a detonation, NS propellant should be processed in low tensile-strength (such as plastic) tubing and containers.

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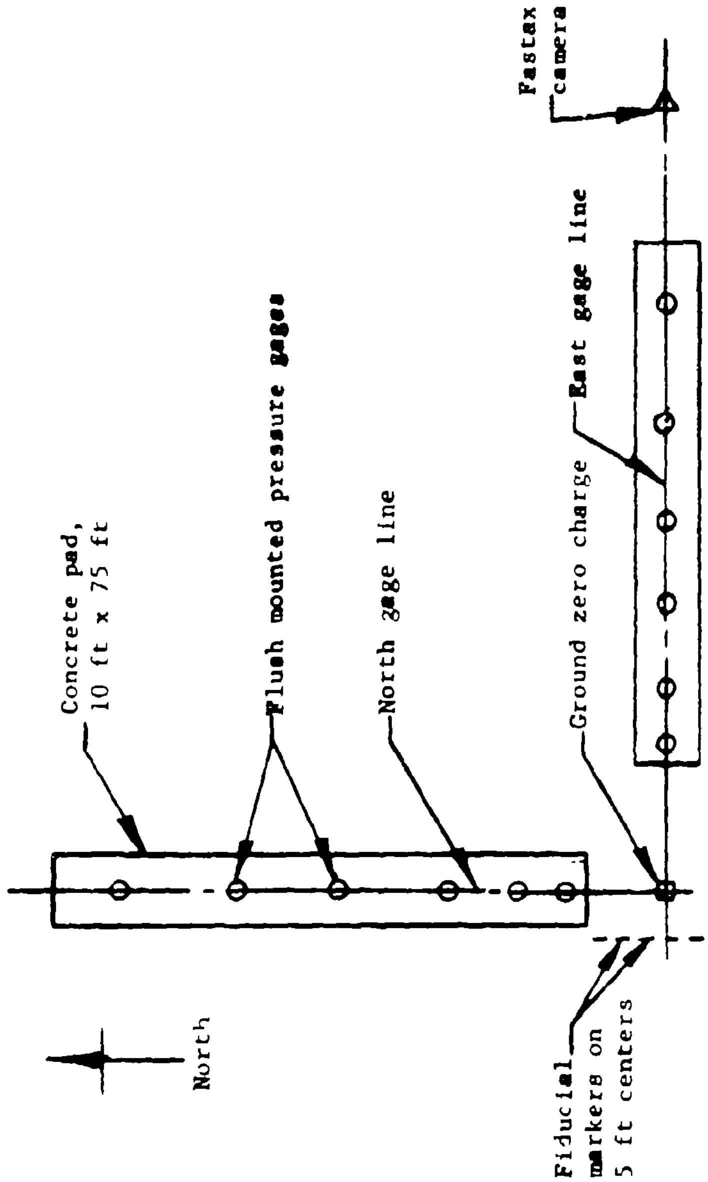


Fig 1 IITRI test area

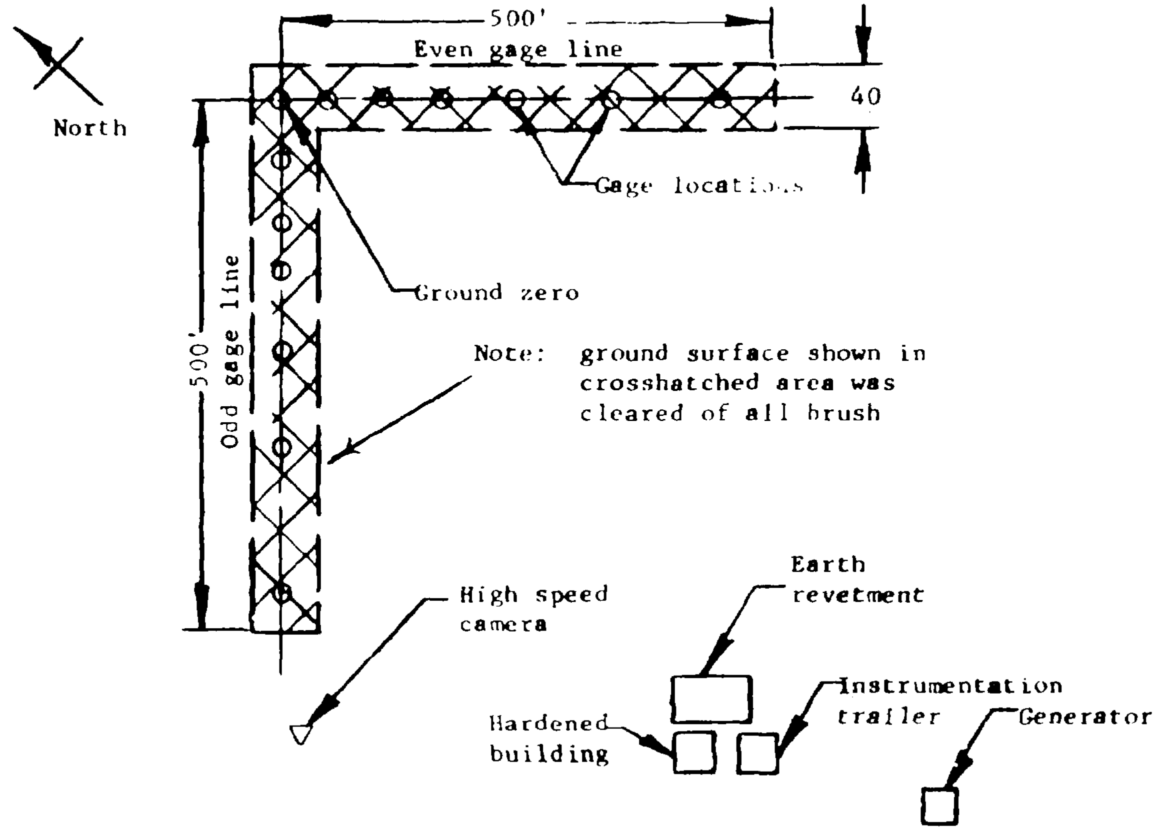


Fig 2 DPG test area

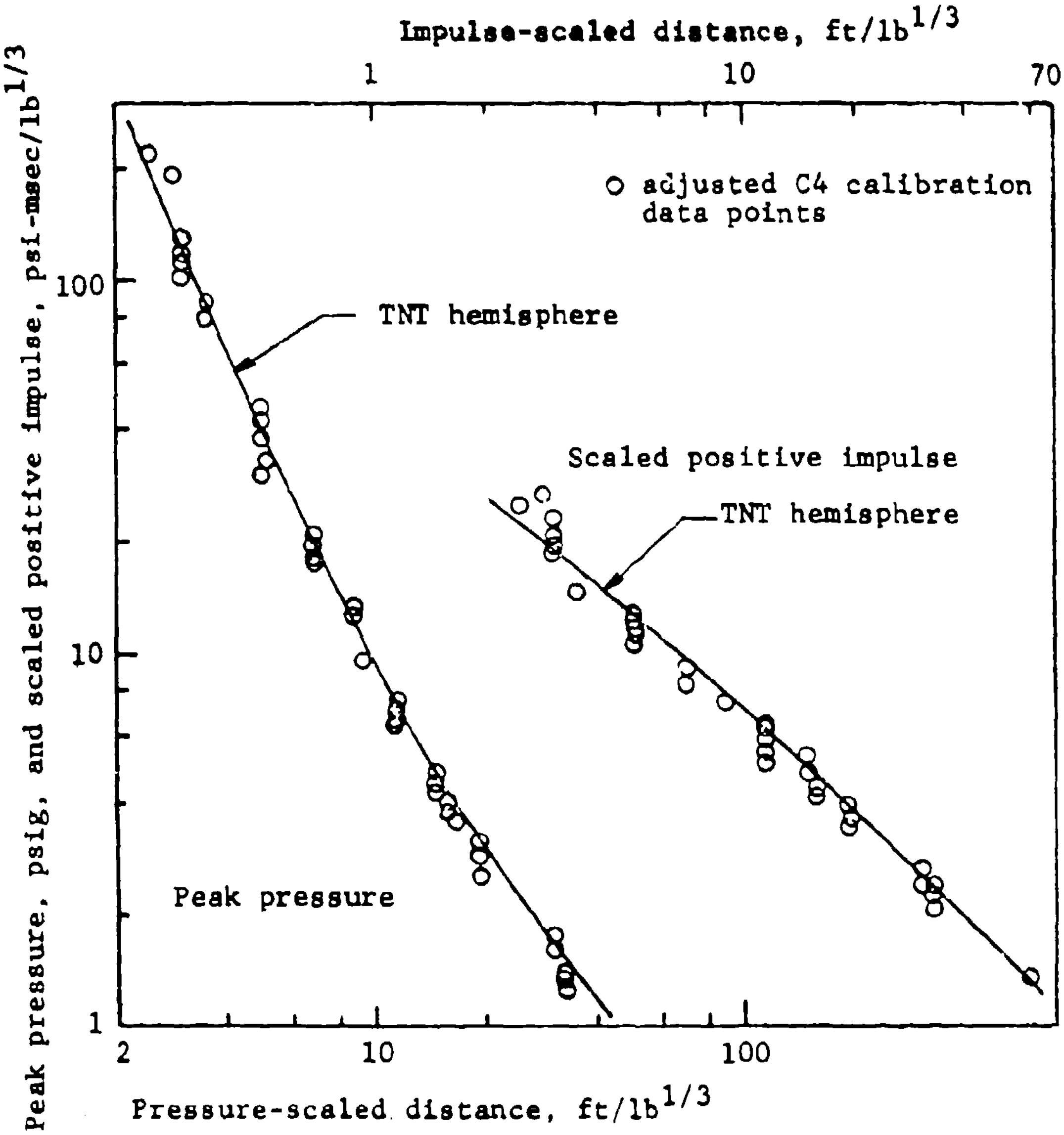


Fig 3 C4 calibration data (adjusted) compared to standard TNT hemisphere pressure and impulse curves

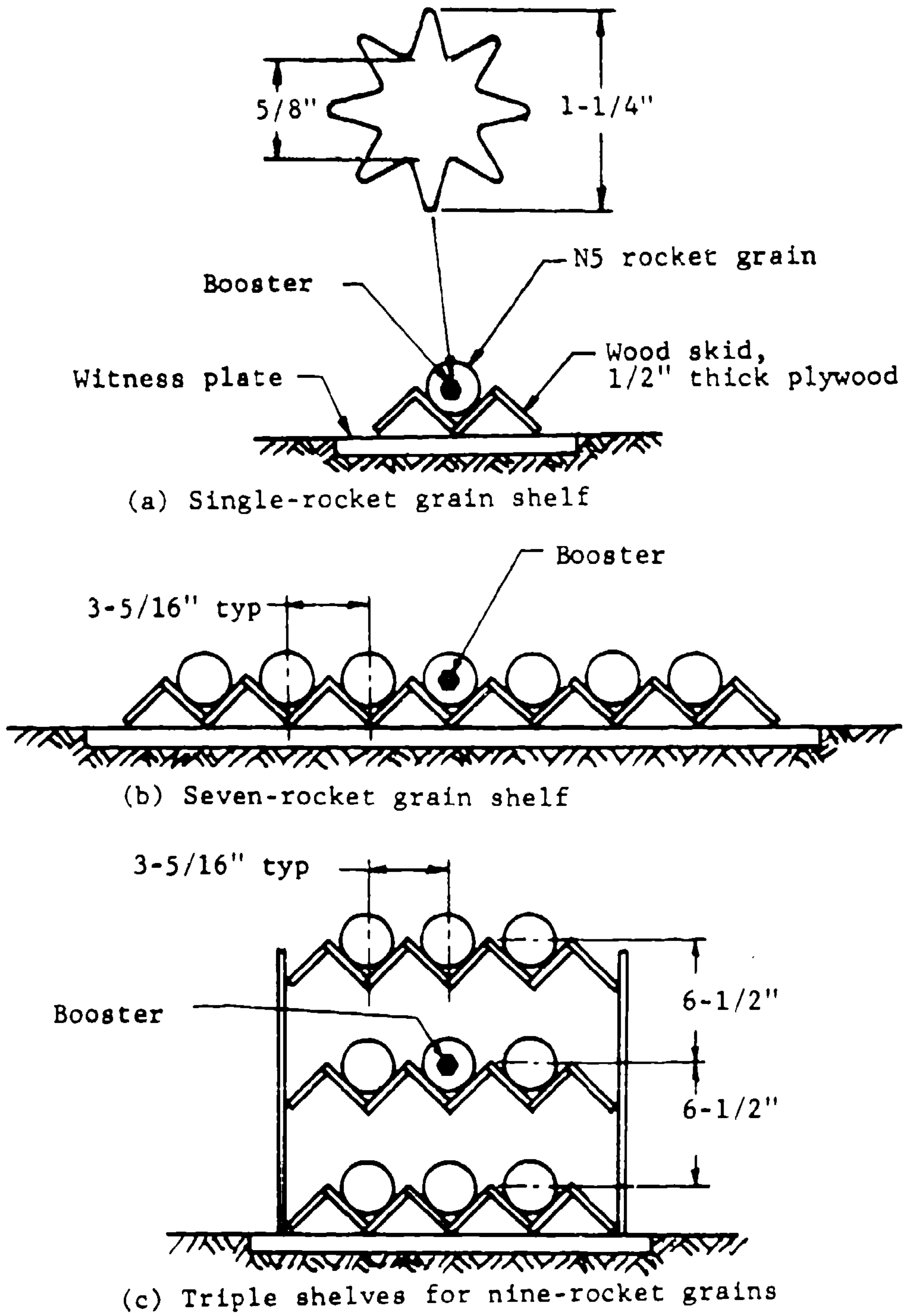


Fig 4 Improvised rocket-grain configurations

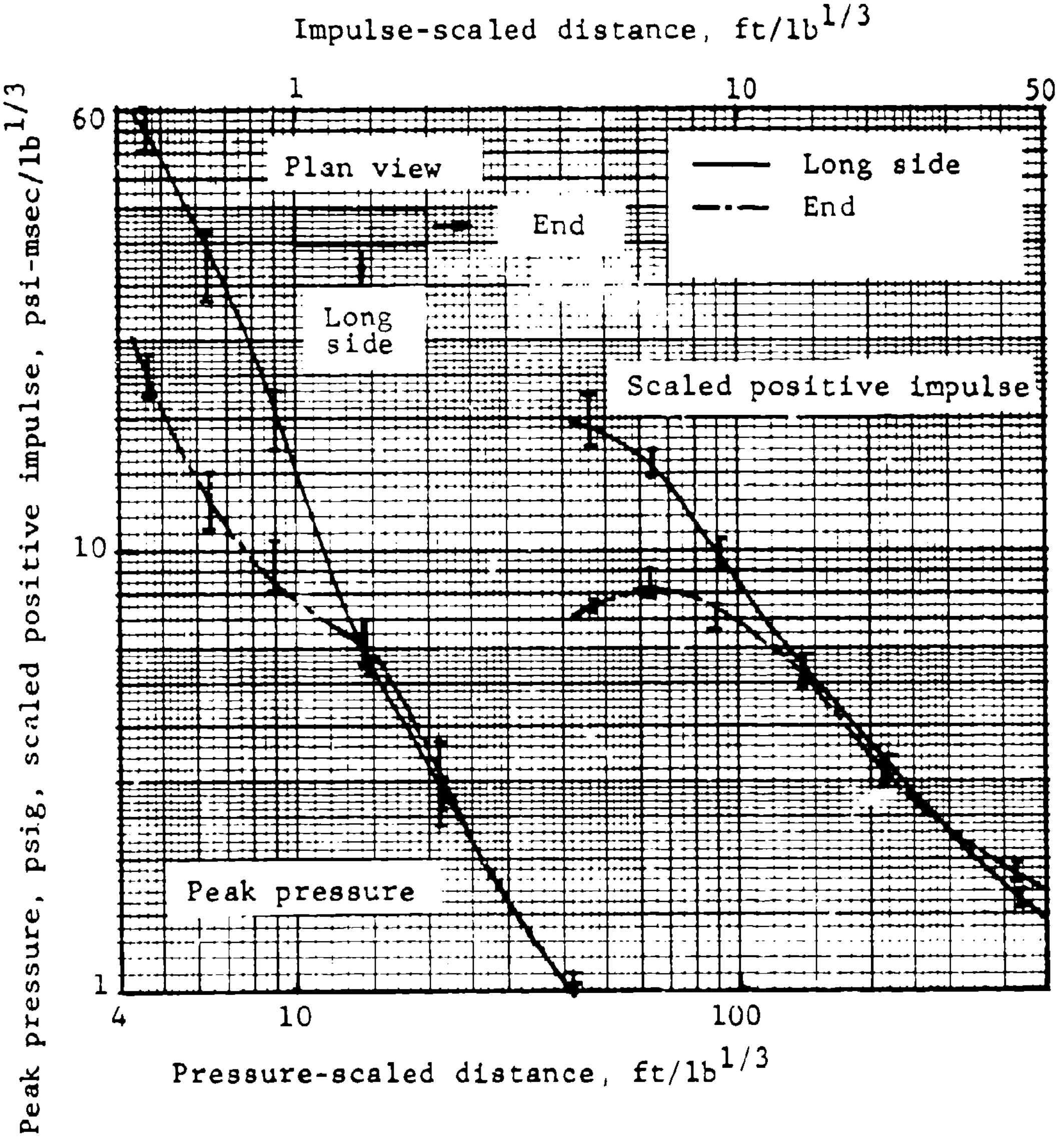


Fig 5 P and I, MK 43-1 rocket grain, one-grain shelf

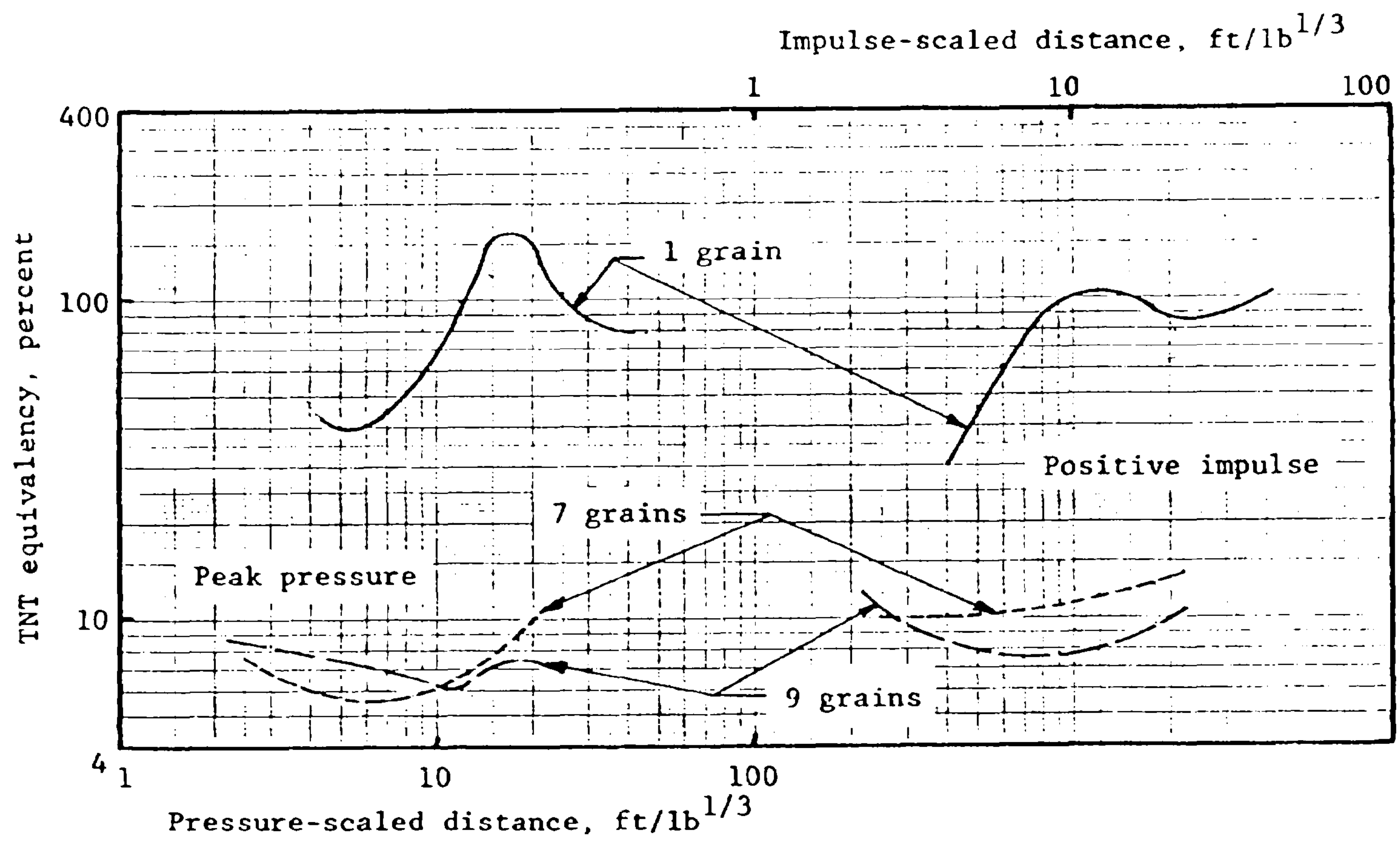


Fig 6 TNT EQ, MK 43-1 rocket grains, end

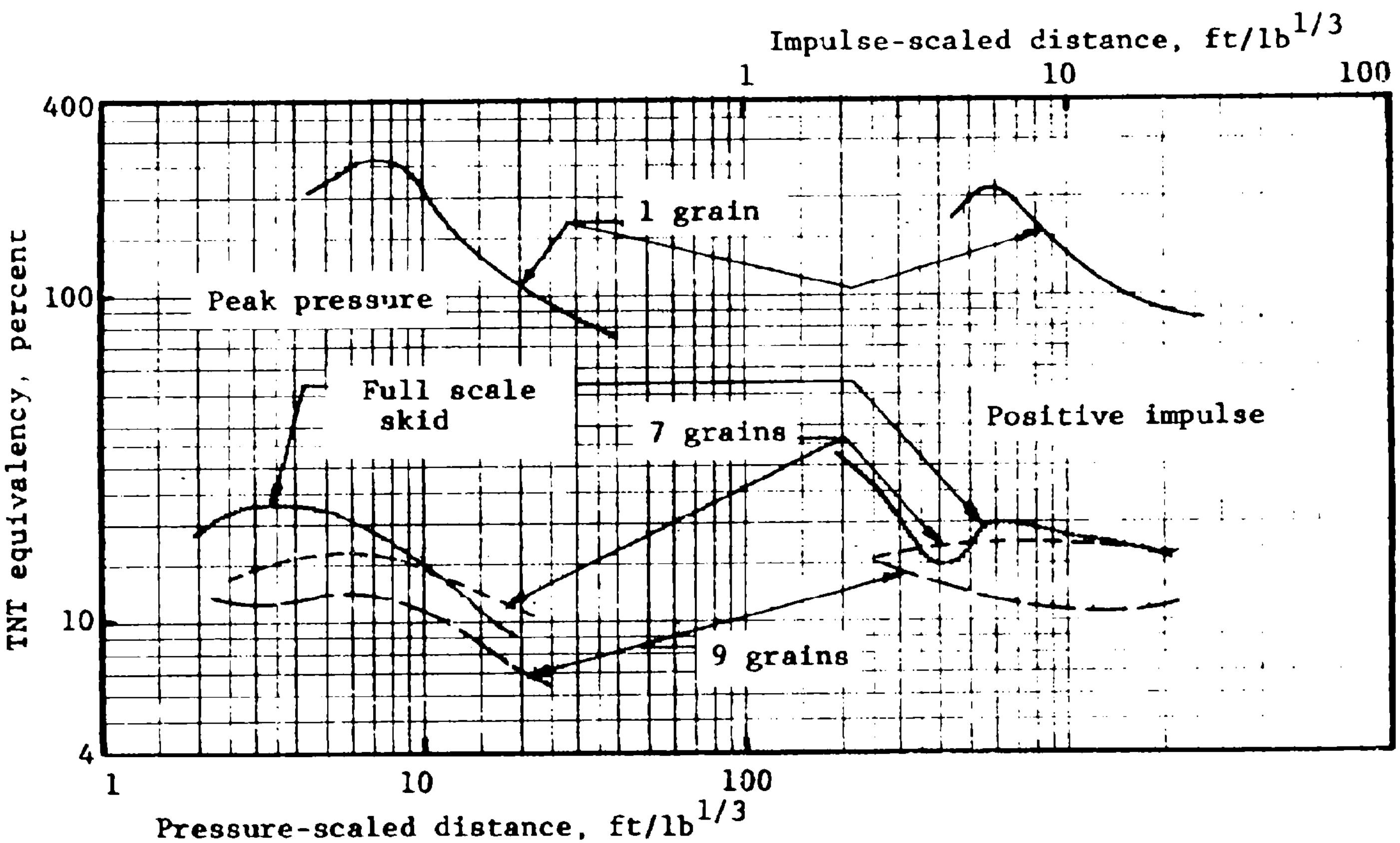


Fig 7 TNT EQ, MK 43-1 rocket grains, long side

Fig 8 Full-scale rocket grain skid

Fig 9   Rocket grain skid posttest

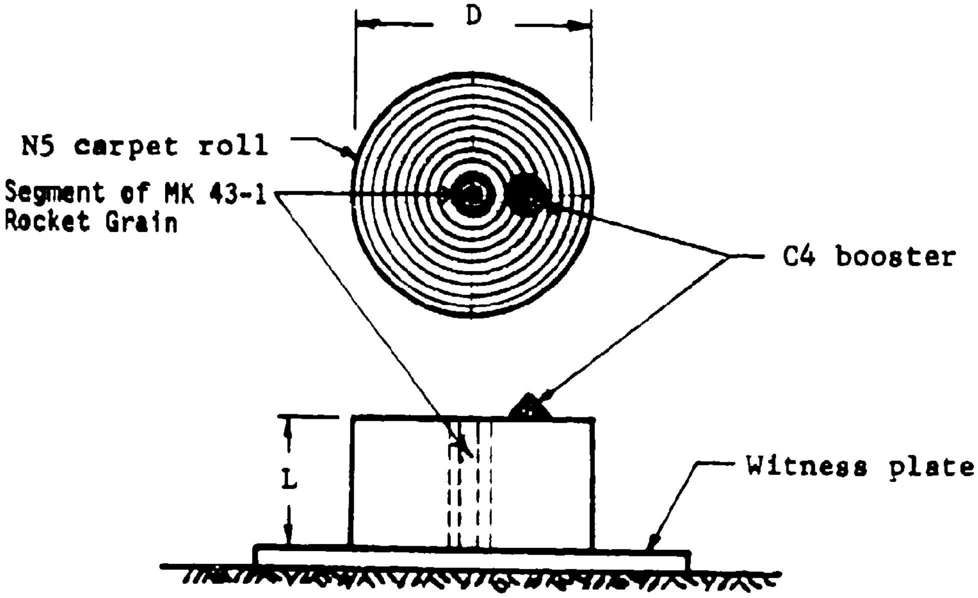


Fig 10 N5 carpet-roll test configuration

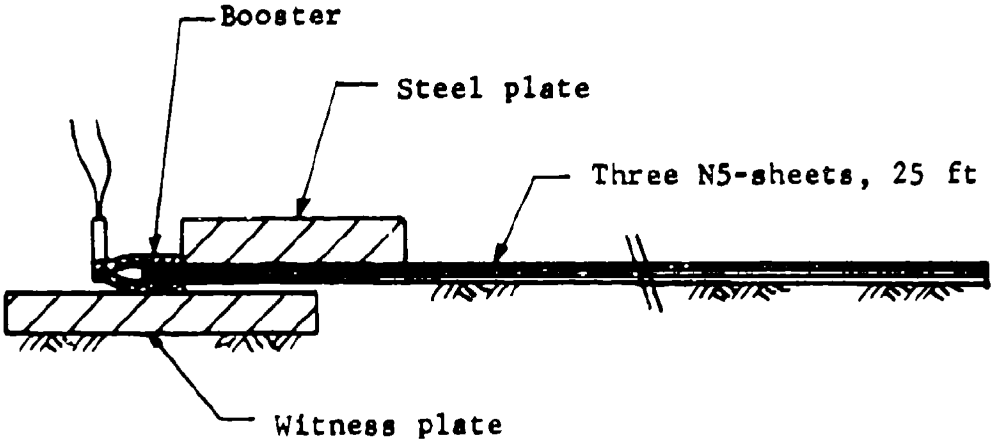


Fig 11 N5 strip test configuration

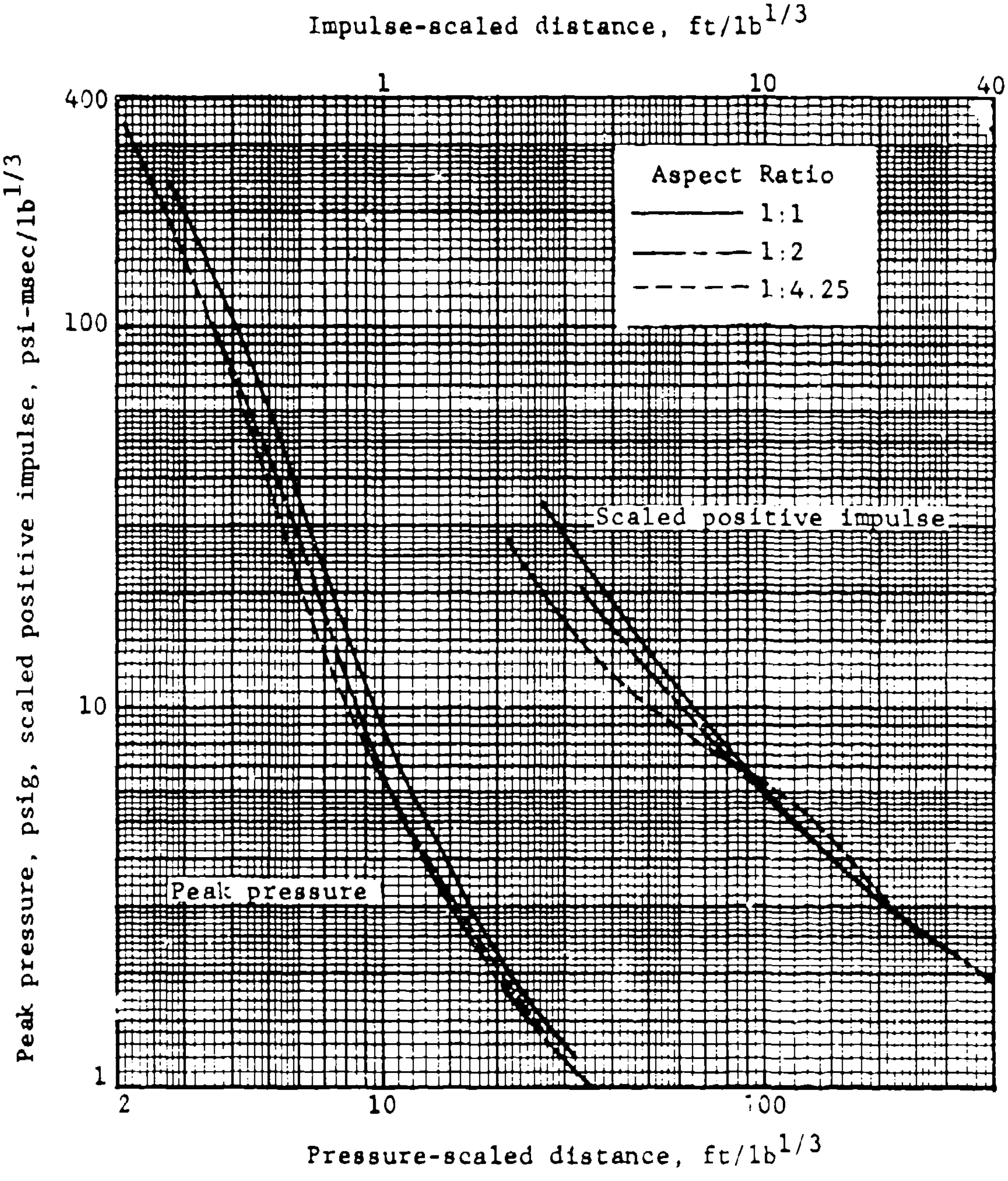


Fig 12 P and I, N5 carpet rolls, aspect ratios of 1:1, 1:2, 1:4.25

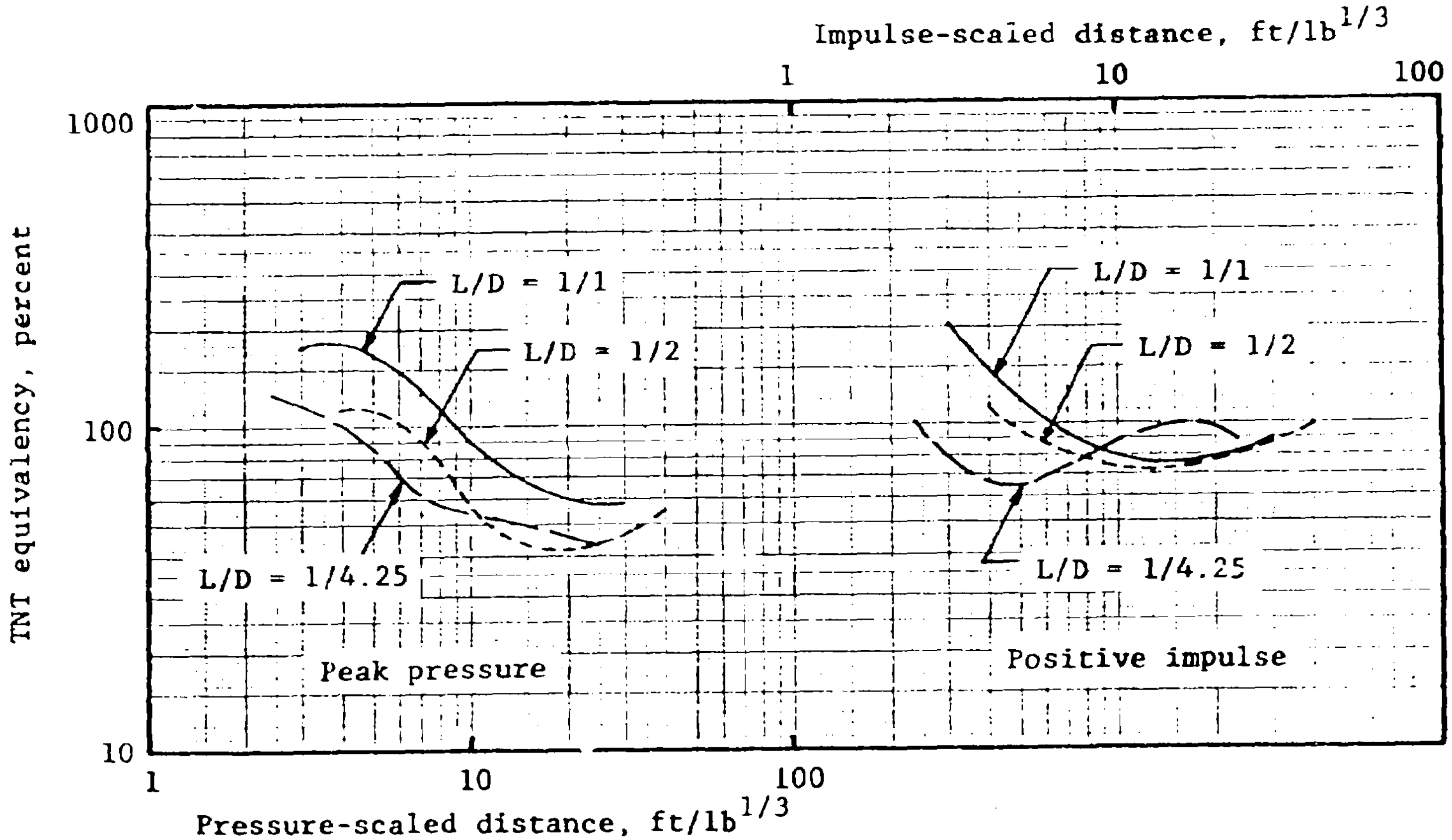


Fig 13 TNT EQ, N5 carpet rolls

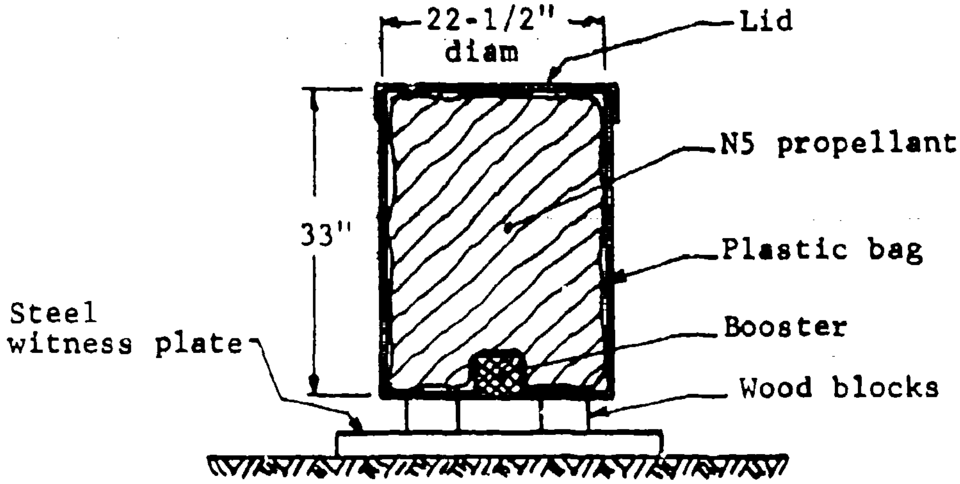


Fig 14 Fiber-drum test configuration

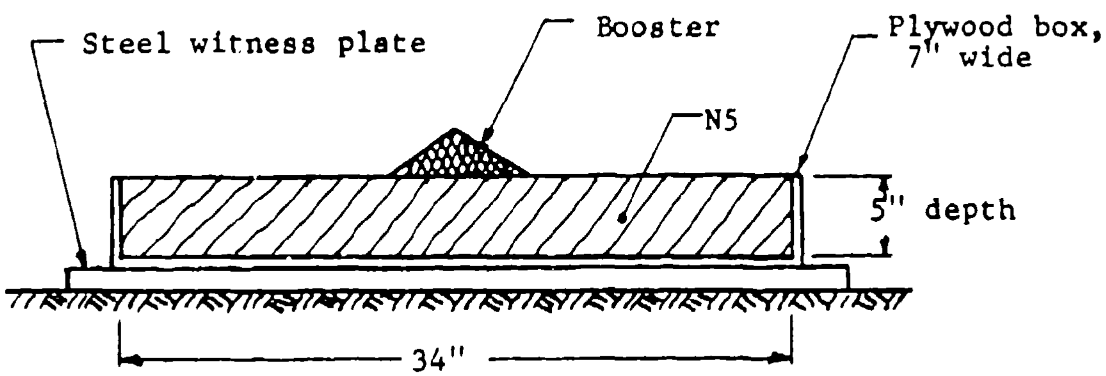


Fig 15 Charging-bucket test configuration

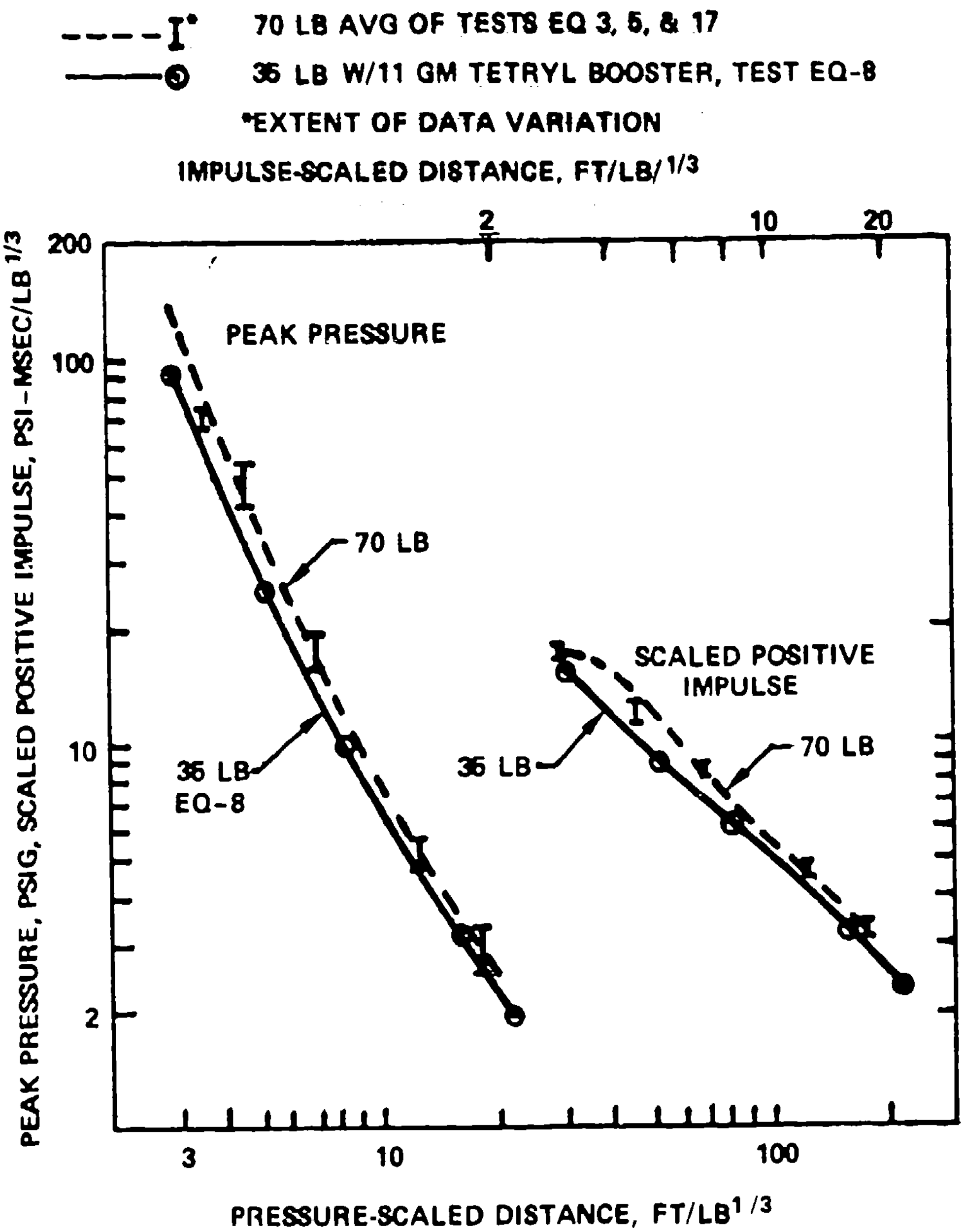


Fig 16 N5 propellant with 10% moisture, fiber drum

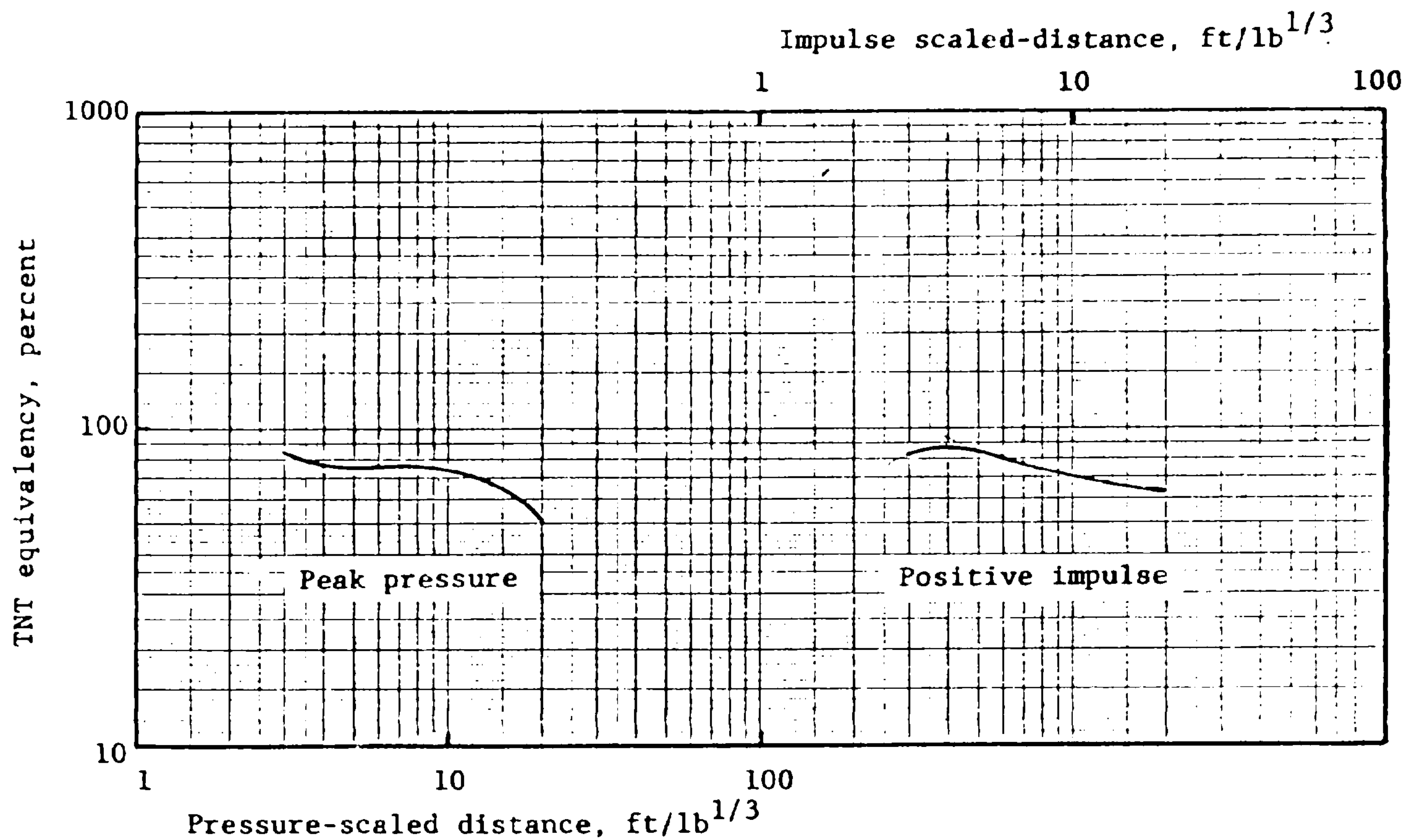


Fig 17 TNT EQ, N5/10% moisture, fiber drum

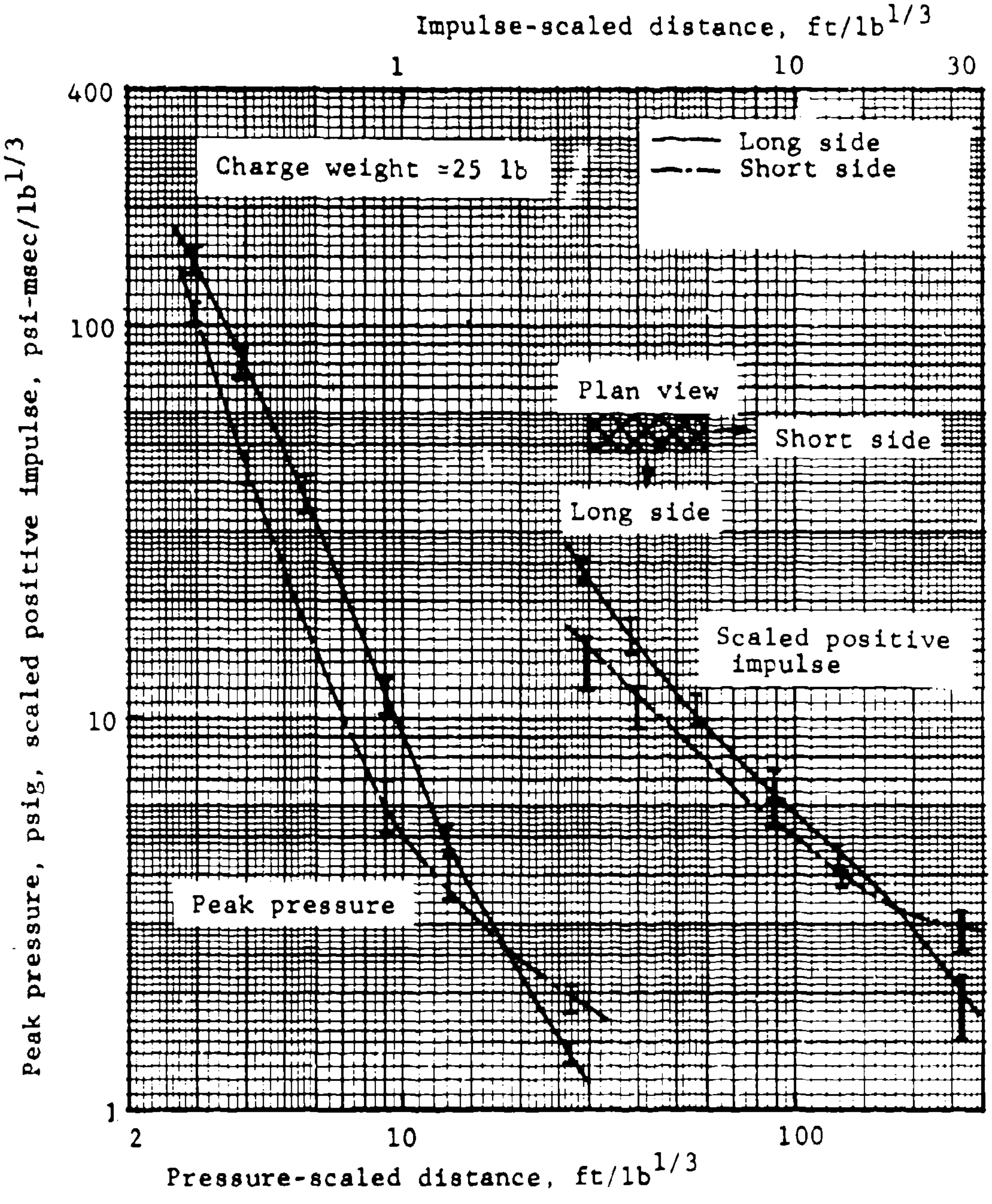


Fig 18 P and I, N5/10% moisture, charging bucket

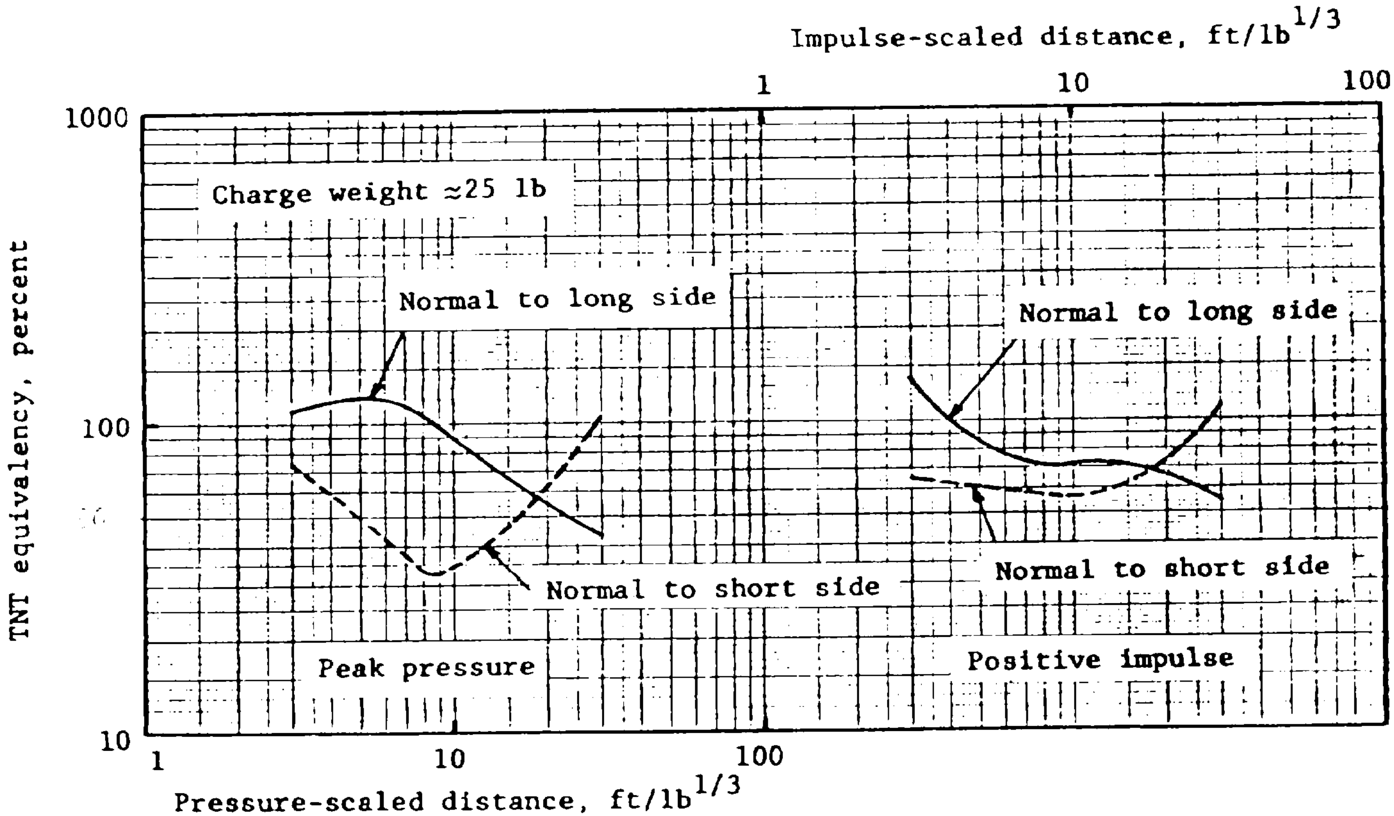


Fig 19 TNT EQ, N5/10% moisture, charging bucket with Comp C4 booster

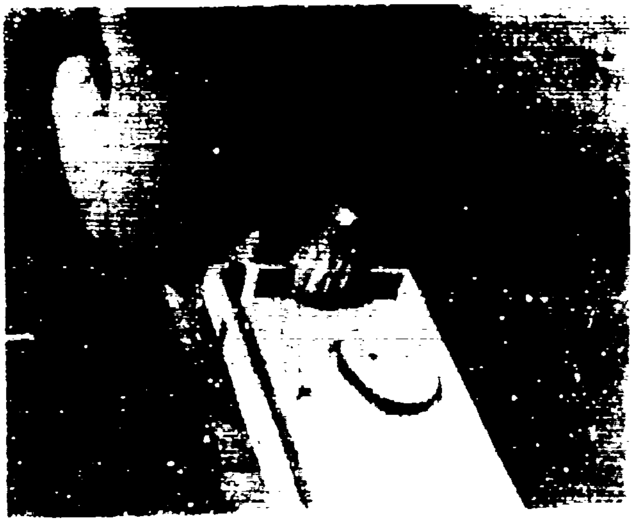


Fig 20   Placement of Detasheet strip booster for conveyor belt configuration

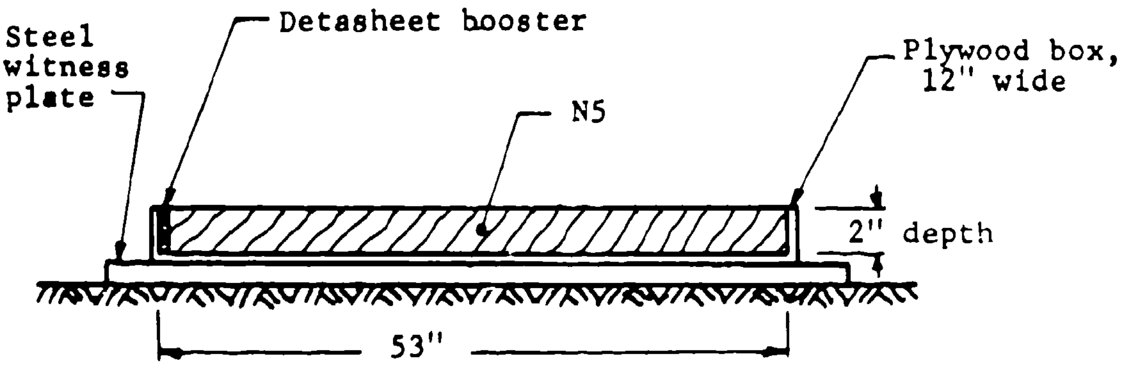


Fig 21   Conveyor belt configuration assembly

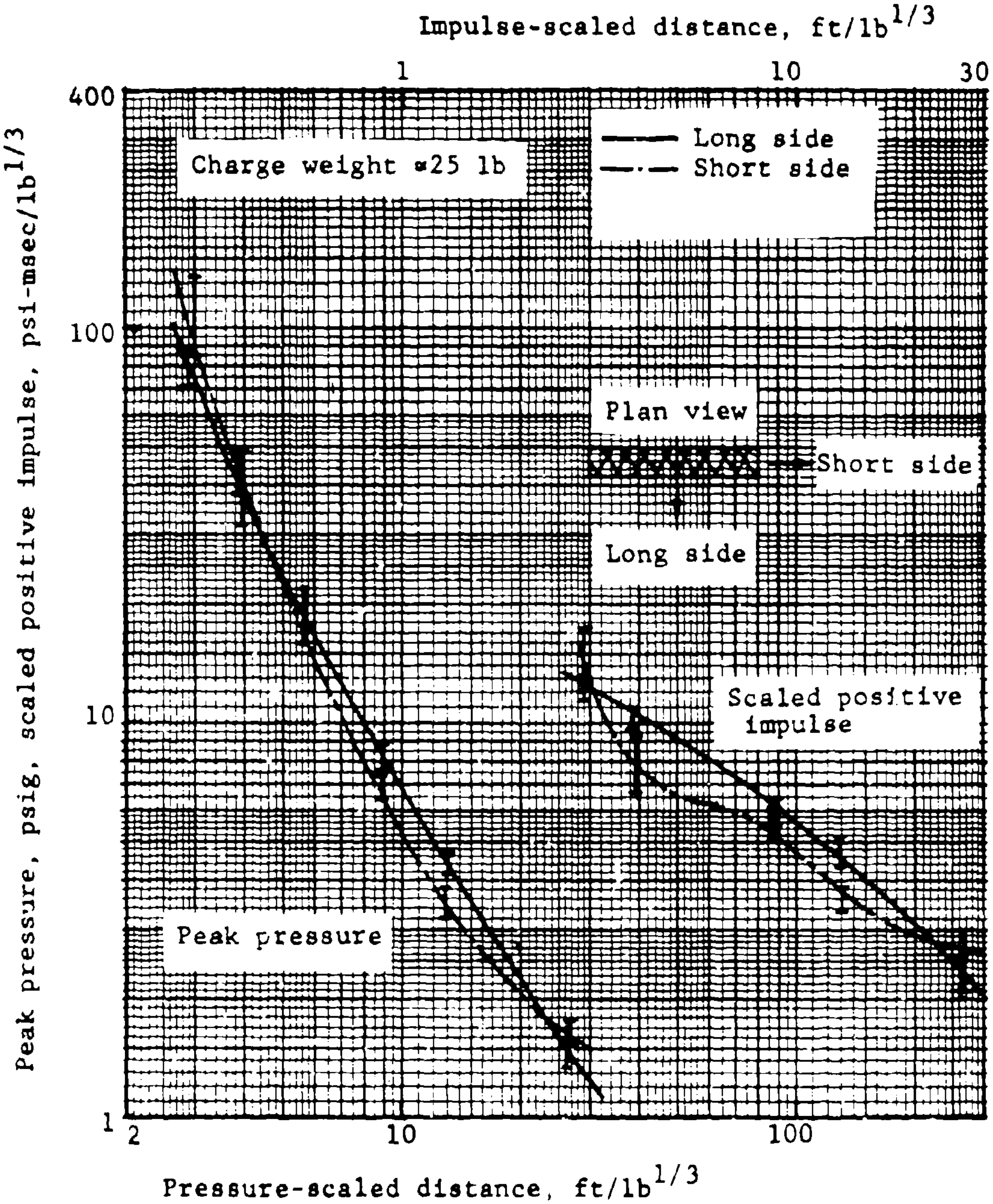


Fig 22 P and I, N5/10% moisture for conveyor belt configuration

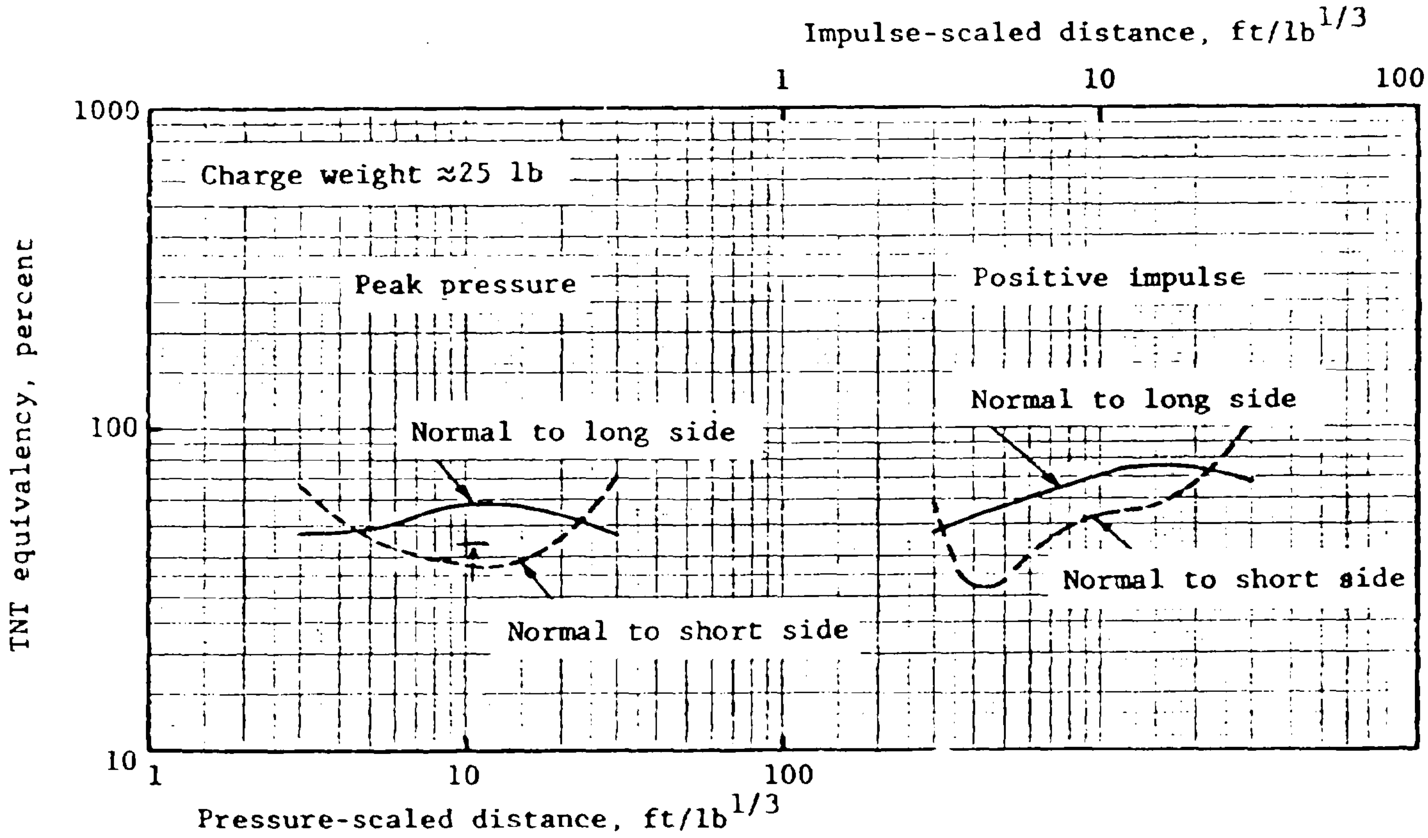


Fig 23 TNT EQ, N5/10% moisture, conveyor belt with Detasheet booster

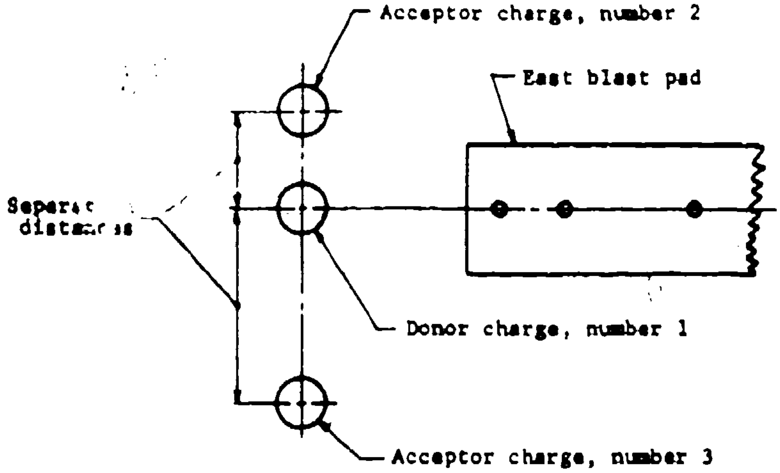


Fig 24 Plan view of sympathetic detonation/ burn test configuration

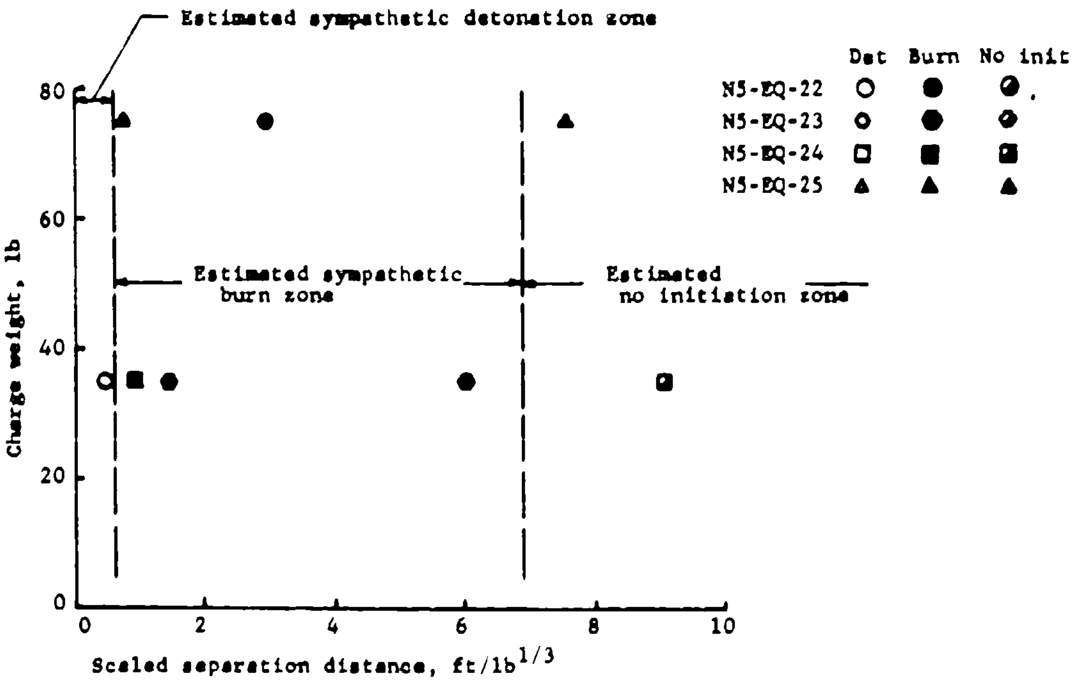


Fig 25 Sympathetic detonation and burn zones

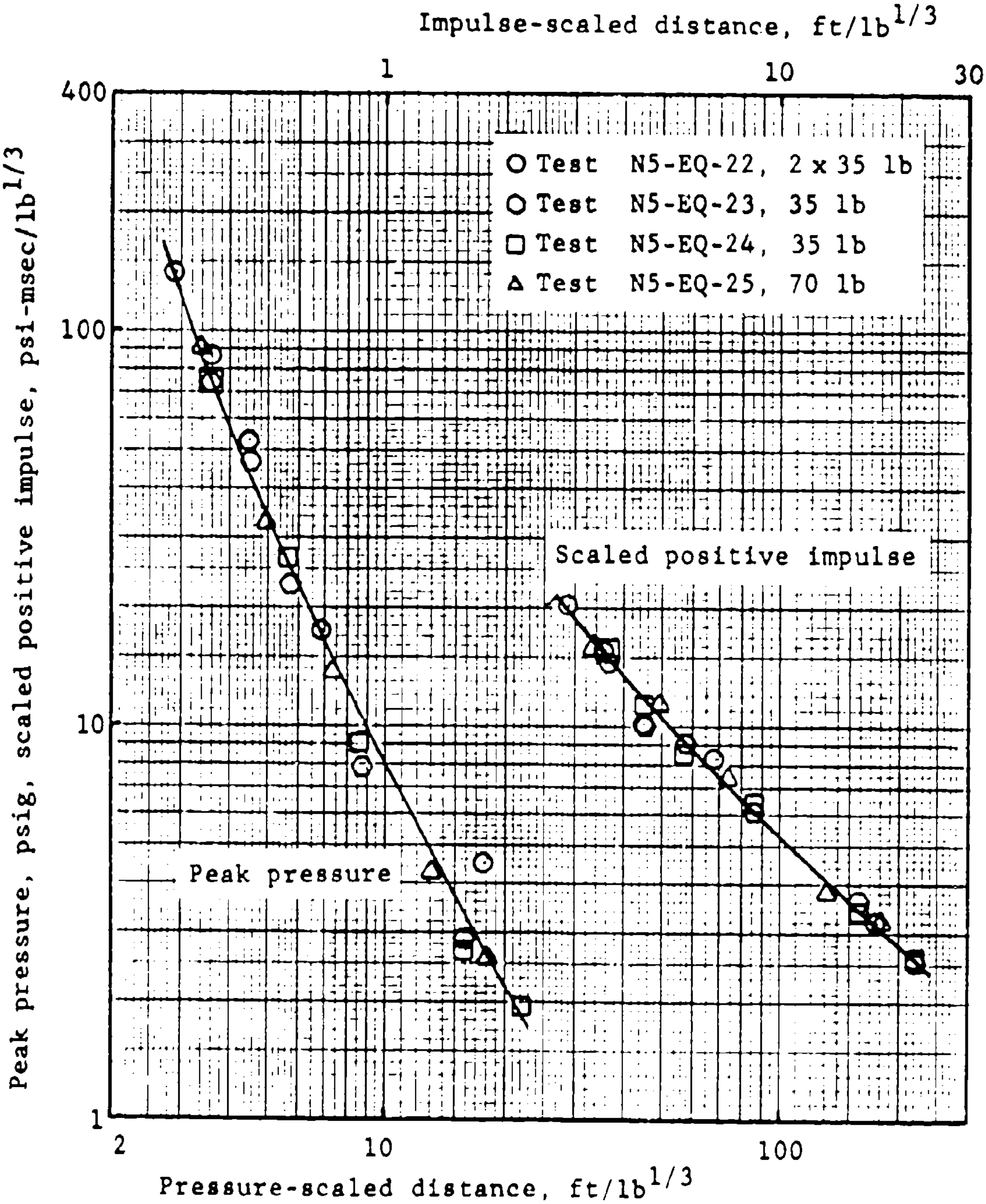


Fig 26 P and I, N5/10% moisture, sympathetic detonation

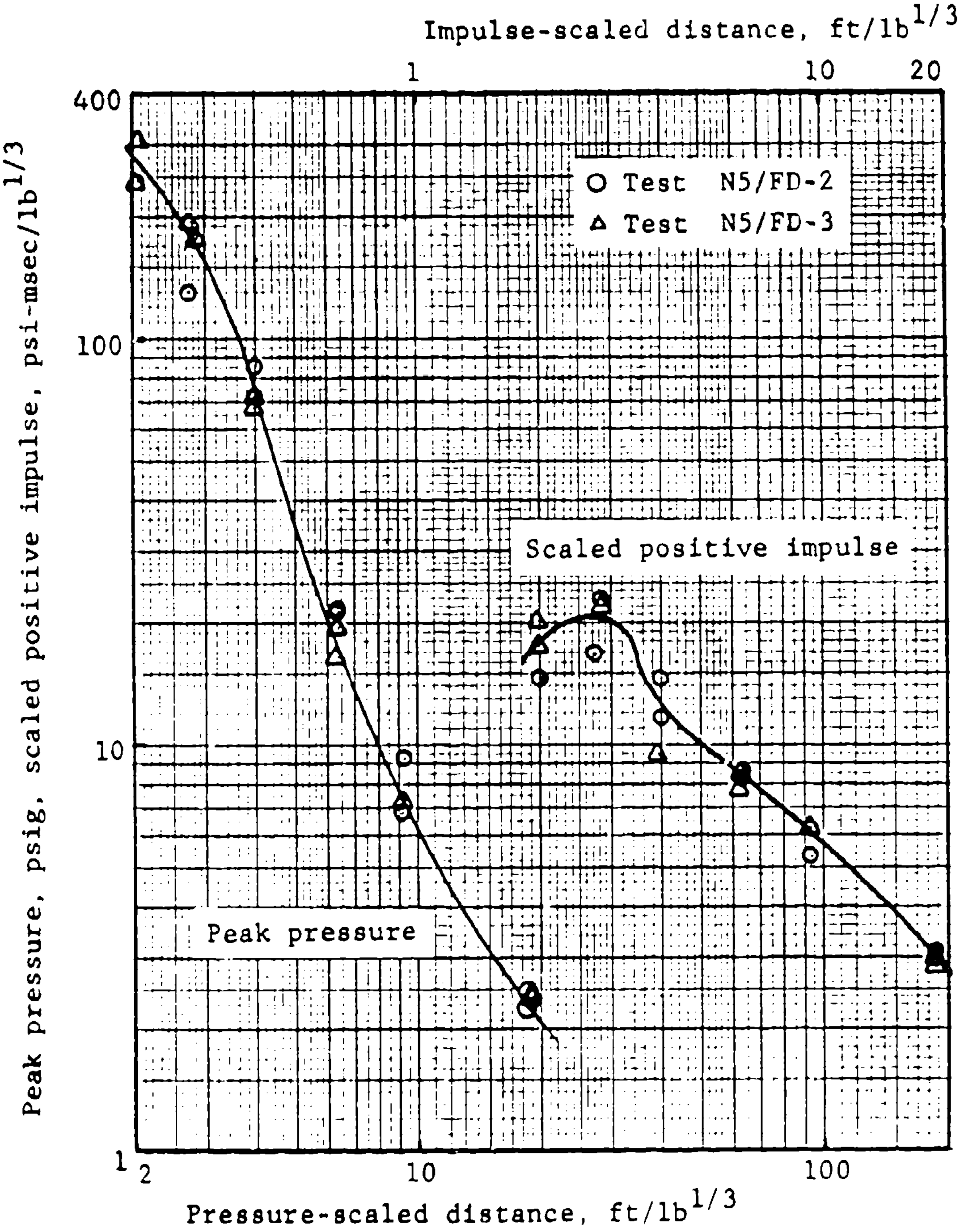


Fig 27 P and I, N5/30% moisture, fiber drum

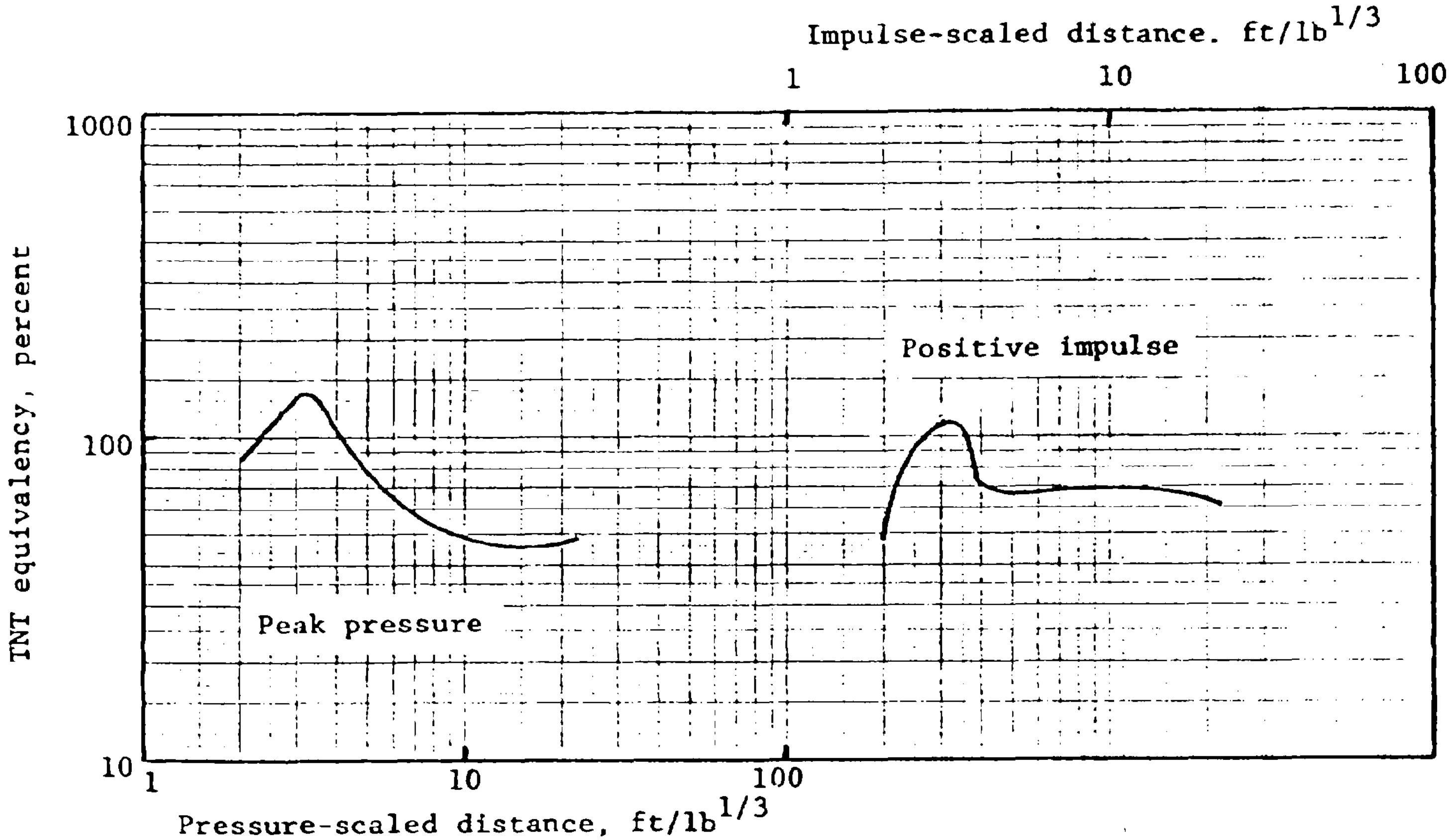
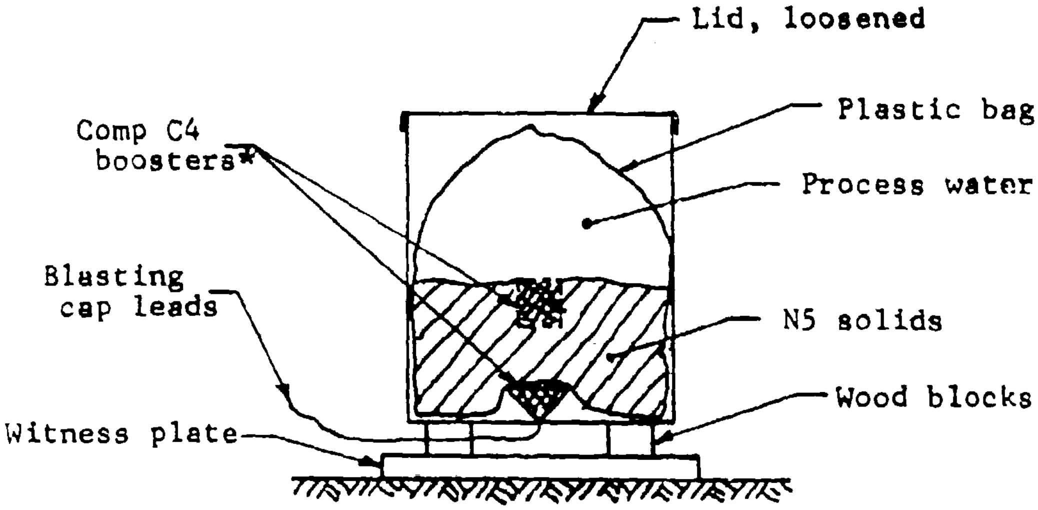


Fig 28 TNT EQ, N5/30% moisture, fiber drum



*Boosters located at bottom for N5-EQ test series and at top for N5/88% test series.

Fig 29 Five-gallon can test configuration

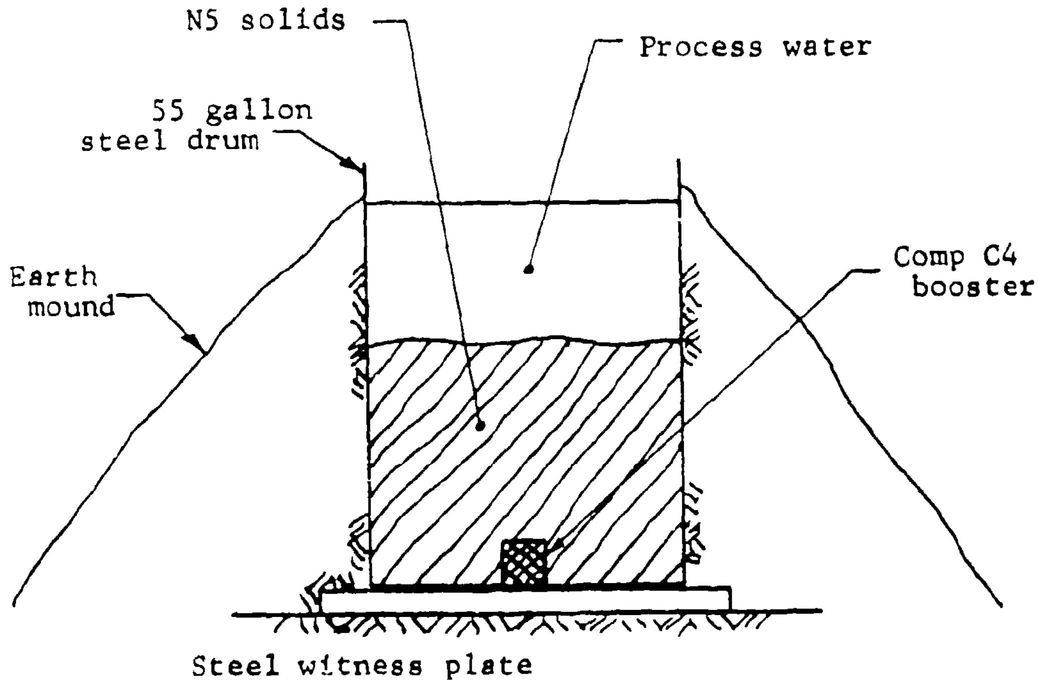


Fig 30 Fifty-five gallon drum test configuration

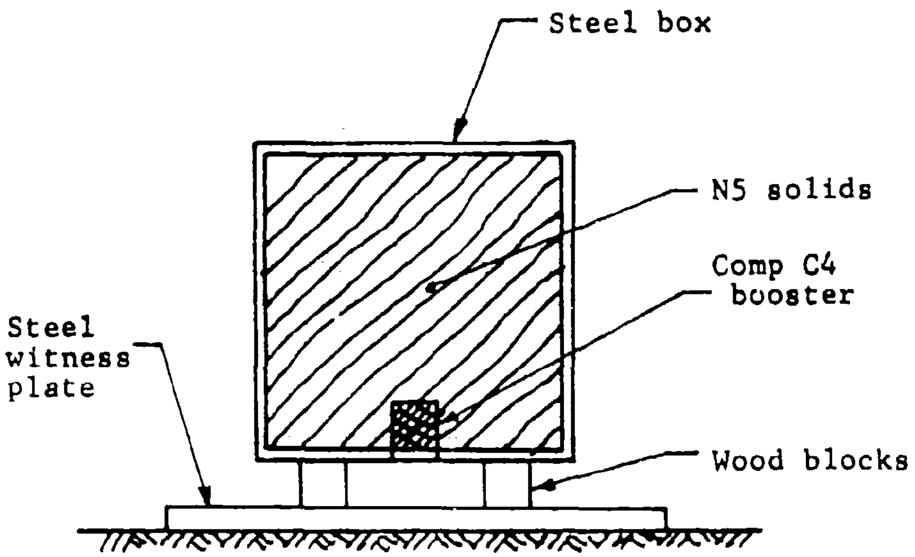


Fig 31 Steel box test configuration

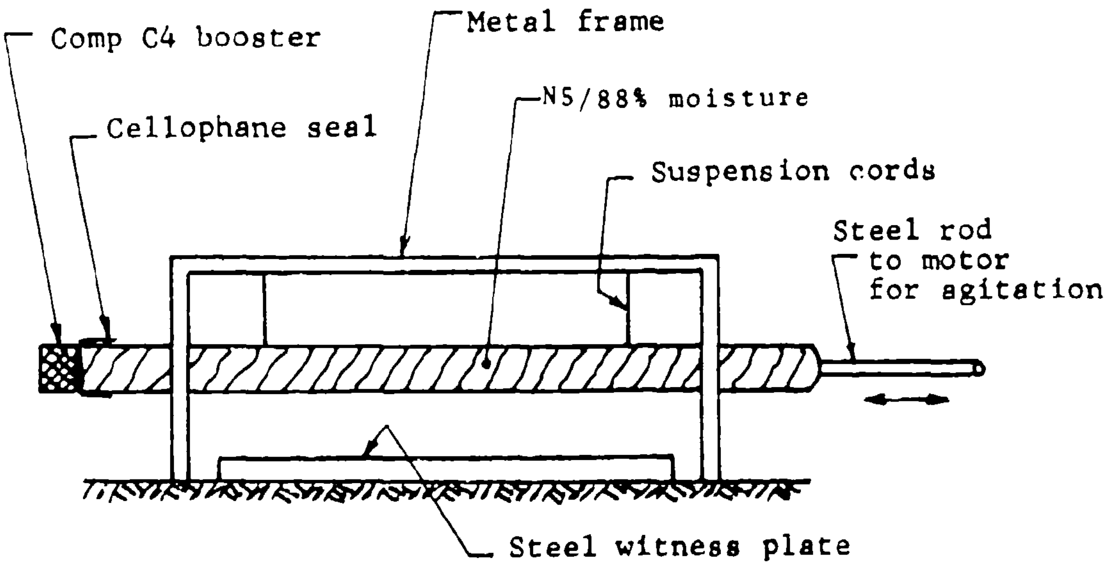


Fig 32 Agitated pipe configuration

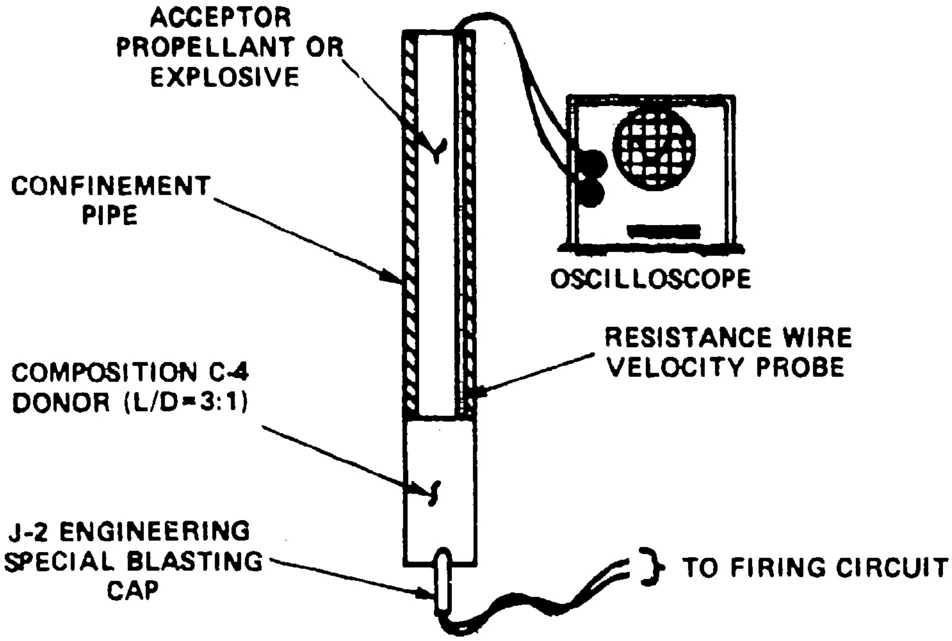


Fig 33 Critical diameter test setup

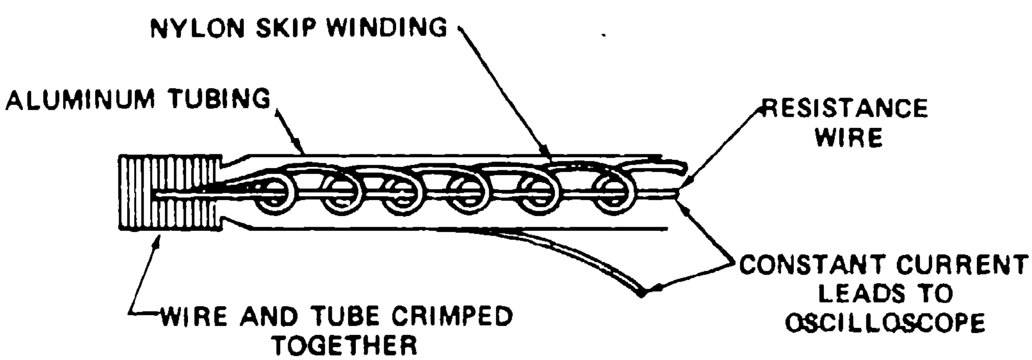


Fig 34 Resistance wire probe test setup

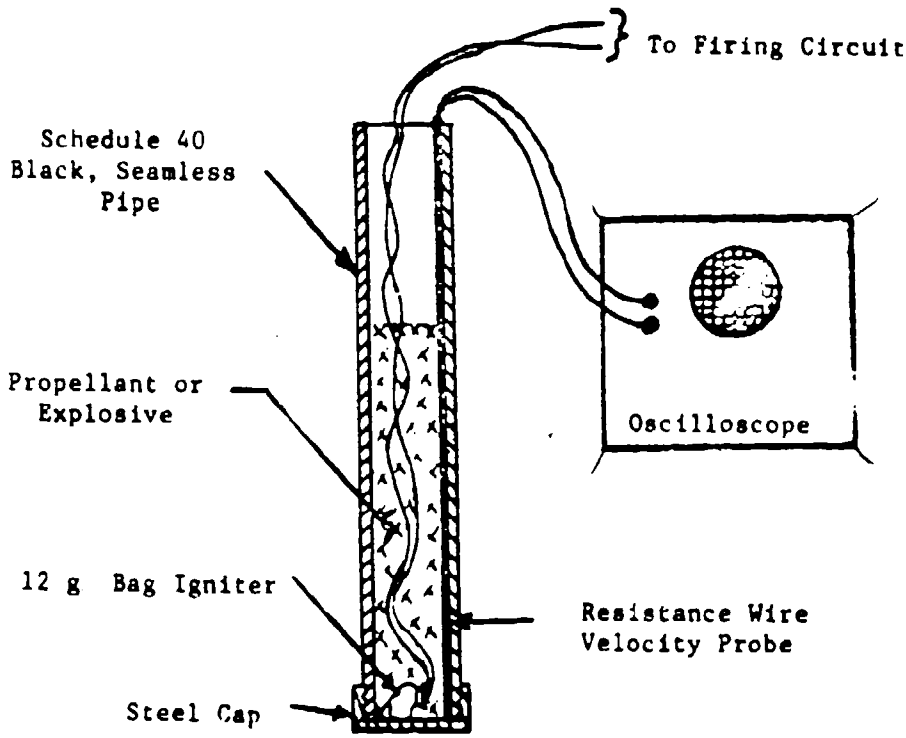


Fig 35 Critical height-to-explosion test setup

APPENDIX

TNT Equivalency Profile of N5 Propellant

NS propellant was tested in a variety of in-process states and configurations as shown in the accompanying illustrations. Blast output was measured and TNT equivalency computed in comparison with the explosive blast output of a surface burst of a hemispherically shaped TNT charge. The results of these computations, in terms of a TNT equivalency profile, are presented in the table and in the figures which follow:

Configuration, material	TNT equivalency, percent							
	$\lambda^a = 2$		$\lambda = 9$		$\lambda = 18$		$\lambda = 40$	
	P	I	P	I	P	I	P	I
<u>NS 10-percent moisture</u>								
Fiber drum, 70 lb	-	-	75	70	55	65	-	-
Charging bucket[b], 25 lb	-/-	-/-	100/35	70/55	60/55	70/70	-/-	-/-
Strip[b], 25 lb	-/-	-/-	55/40	70/50	55/45	75/60	-/-	-/-
<u>NS 30-percent moisture</u>								
Fiber drum, 70 lb	85	58	50	70	45	65	-	-
<u>NS 88-percent process water</u>	No ignition							
<u>NS 2.75-inch rocket grains</u>								
1 grain[b], 6.25 lb	-/-	-/-	60/250	95/145	160/115	90/90	80/65	100/85
Full-scale skid, 104 grains	20	35	15	20	10	15	-	-
<u>NS carpet roll</u>								
L/D = 1/1, 22 lb	-	-	100	80	60	75	-	-
L/D = 1/2, 11 lb	-	-	65	75	40	100	55	100
L/D = 1/4.25, 48 lb	-	-	55	85	45	80	-	-
<u>NS sheets</u>	Burned, no detonation							

[a] λ, scaled distance, ft/lb$^{1/3}$
P, peak pressure TNT equivalency
I, positive impulse TNT equivalency

[b] direction normal to long side/end or long side/short side

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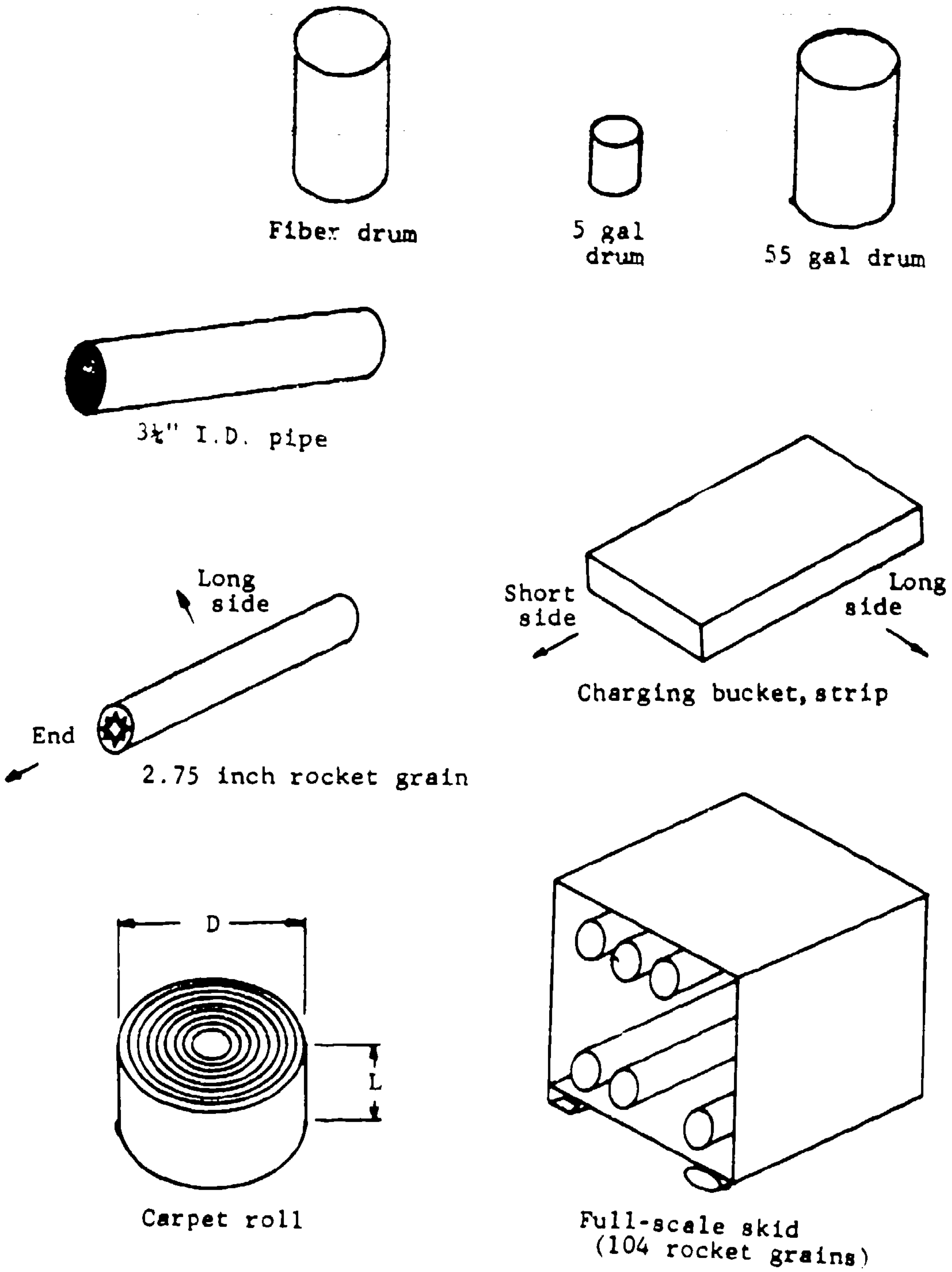
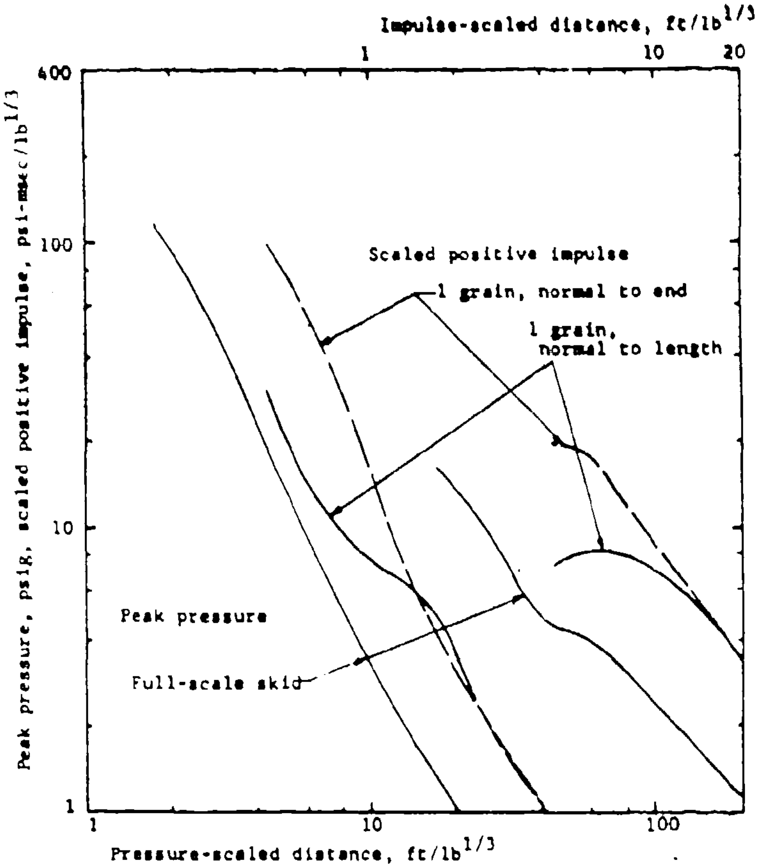
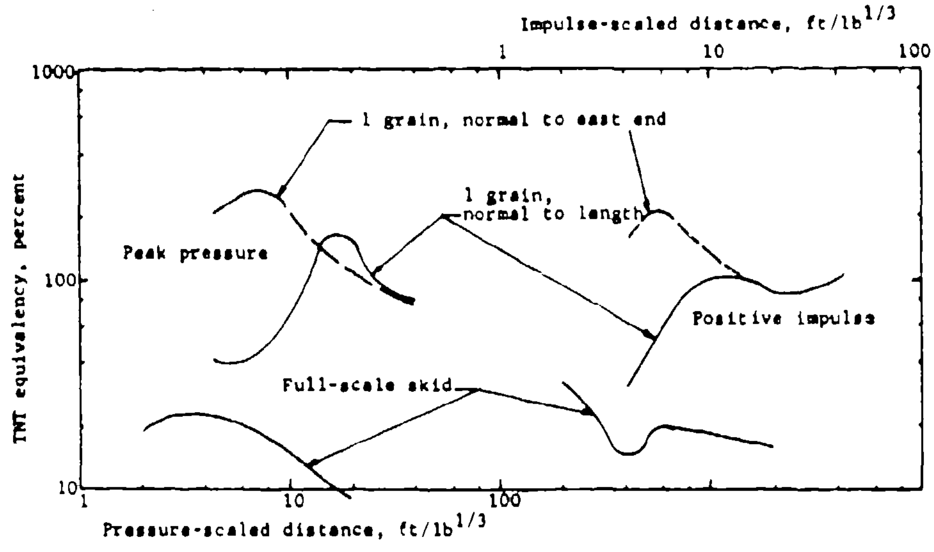


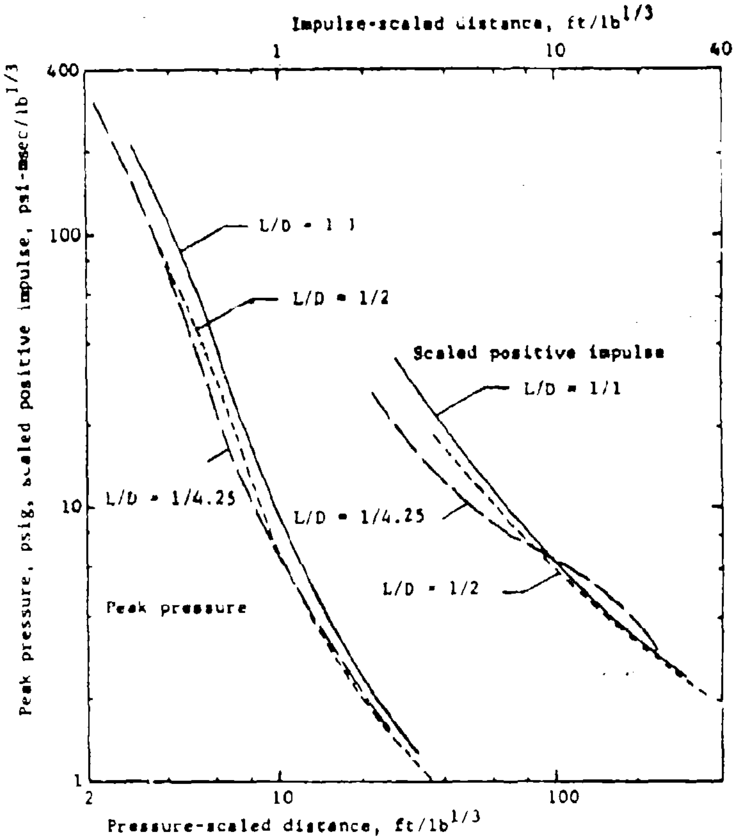
N5 propellant test containers



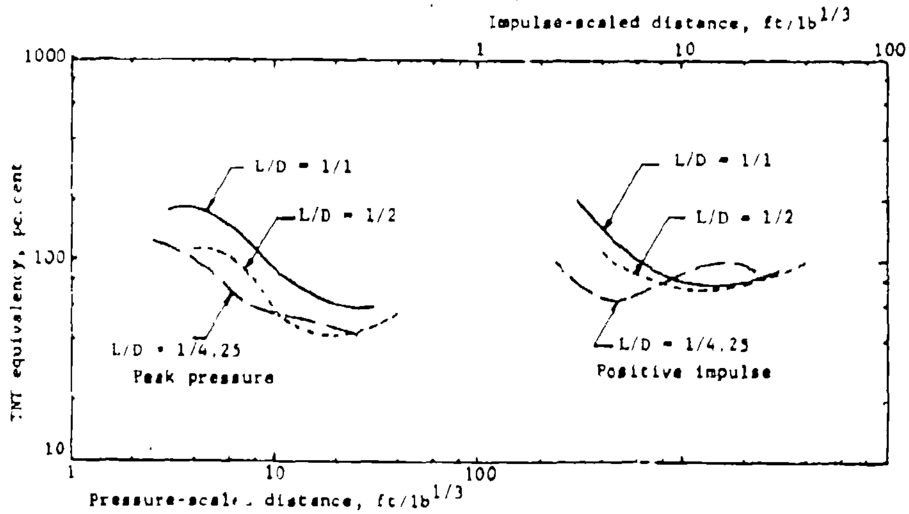
Peak pressure and positive impulse, N5, 2.75 inch rocket grains



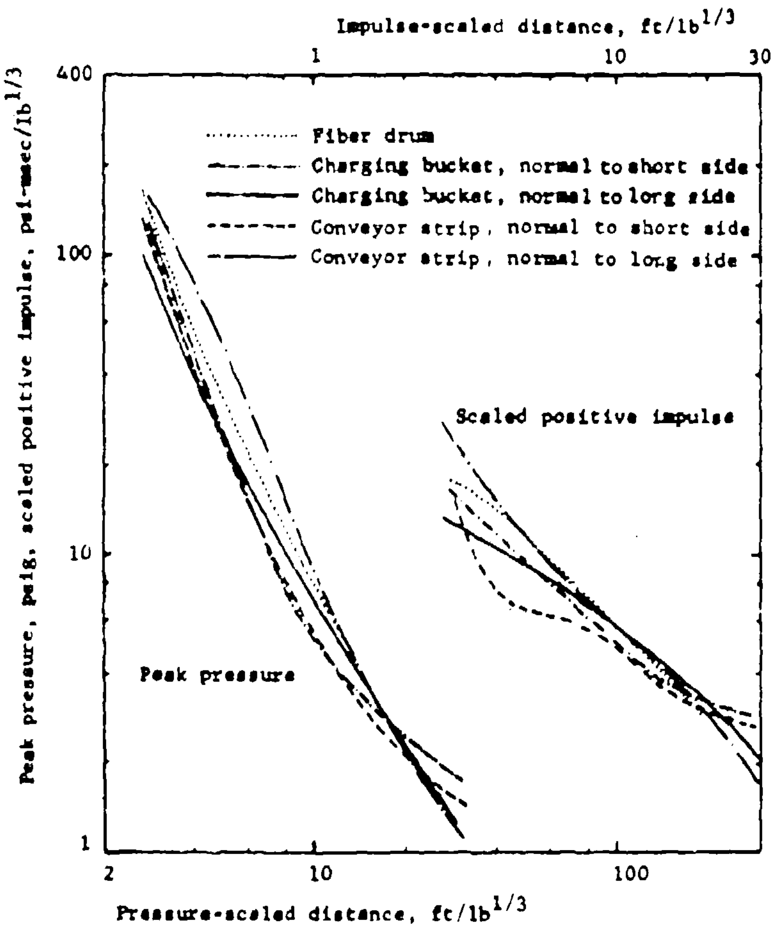
TNT equivalency, N5, 2.75-inch rocket grains



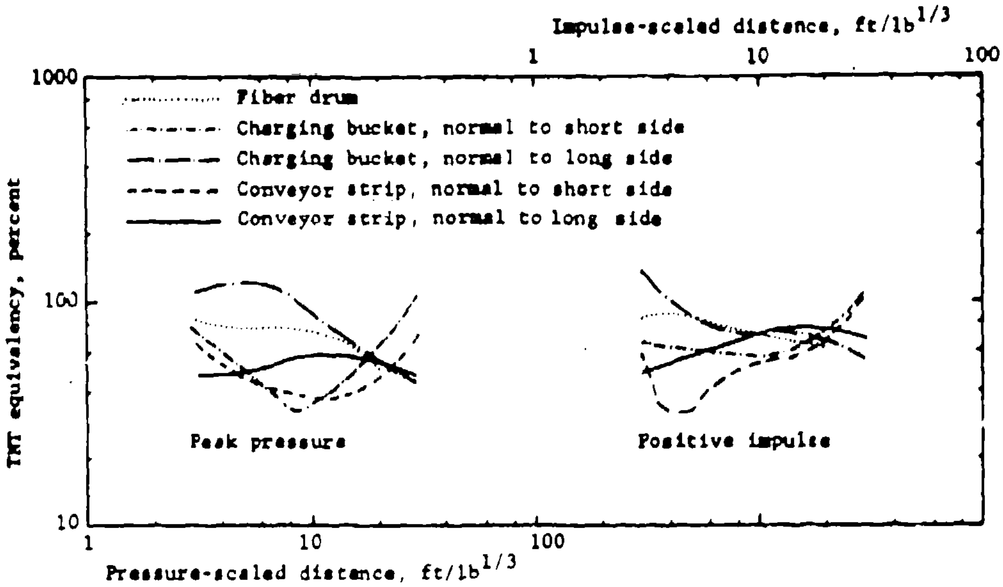
Peak pressure and positive impulse, N5 carpet roll



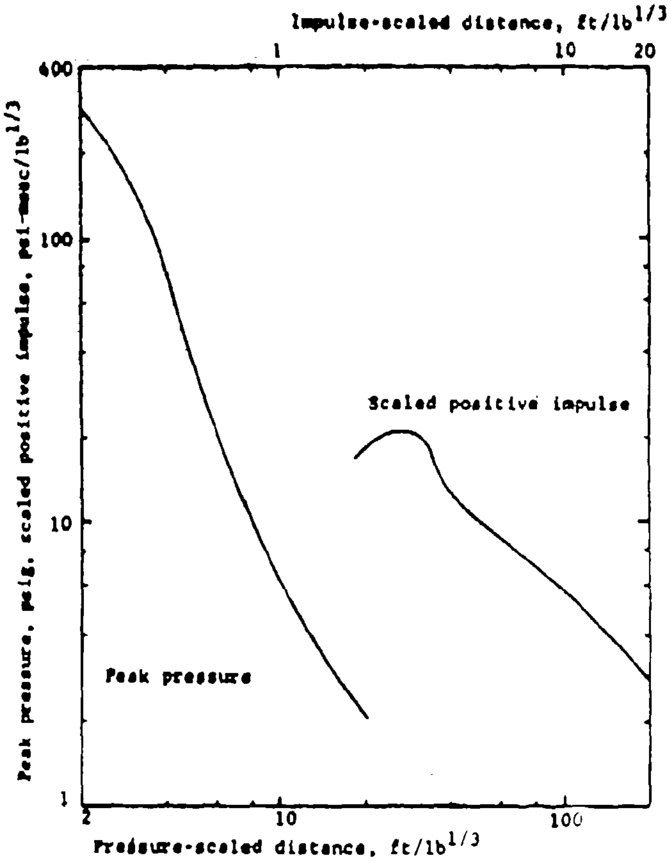
TNT equivalency, N5 carpet roll



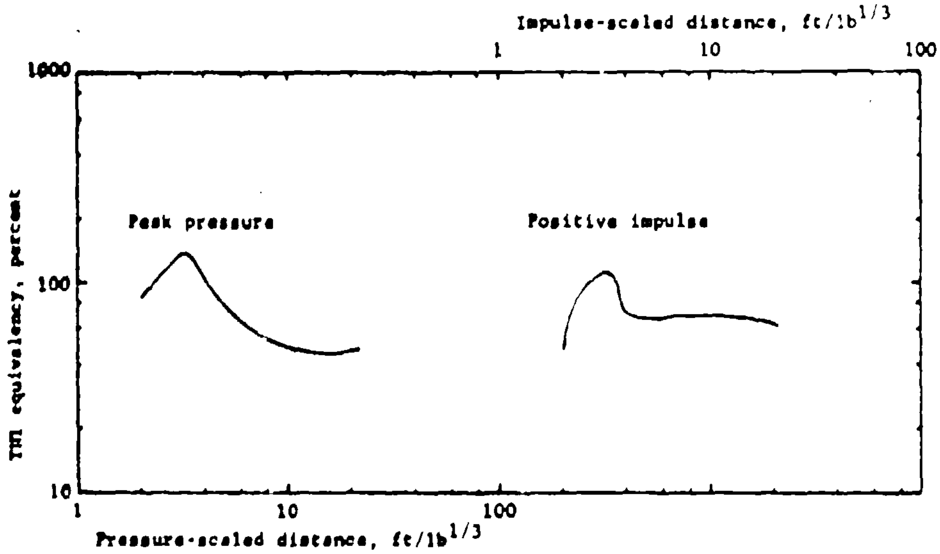
Peak pressure and positive impulse, N5/10-percent moisture



TNT equivalency, N5/10-percent moisture



Peak pressure and positive impulse, N5/30-percent moisture



TNT equivalency, N5/30-percent moisture

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